

## Rebekka M. Wachter, PhD

Professor  
School of Molecular Sciences  
Center for Bioenergy and Photosynthesis  
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### EDUCATION

**Ph.D. in Chemistry**, 06/1996

University of Oregon, Department of Chemistry and Institute of Molecular Biology, Eugene, OR.  
“Energetics of radical redox catalysis in galactose oxidase, using a tyrosine-cysteine cross-linked radical site and an enzyme-bound copper.”

Advisor: Dr. Bruce P. Branchaud, Department of Chemistry

**B.A. (Hon.) in Biochemistry and Molecular Biology**, 06/1986

University of California Santa Cruz.

### PROFESSIONAL POSITIONS

**Professor**, 08/2016 – present

School of Molecular Sciences, Center for Bioenergy and Photosynthesis,  
Arizona State University, Tempe, AZ

**Visiting Scientist**, 05 – 08/2015

Max Planck Institute of Biochemistry, Martinsried, Germany

**Associate Professor**, 05/2007 – 08/2016

Department of Chemistry and Biochemistry, Center for Bioenergy and Photosynthesis,  
Arizona State University, Tempe, AZ

**Visiting Scientist**, 01 – 05/2008

Technical University Munich, Germany

**Assistant Professor**, 08/2001 – 05/2007

Department of Chemistry and Biochemistry,  
Arizona State University, Tempe, AZ

**Postdoctoral Research Associate**, 1996 – 2001

Department of Physics and Institute of Molecular Biology, University of Oregon, Eugene, OR  
Advisor: Dr. S. James Remington, Department of Physics

**PhD Student**, 1991 – 1996

Department of Chemistry and Institute of Molecular Biology, University of Oregon, Eugene, OR

**Senior Research Associate**, 1988 – 1991

California Biotechnology Inc. (Scios Nova Inc.), Mountain View, CA

**Research Associate**, 1987 – 1988

California Biotechnology Inc. (Scios Nova Inc.), Mountain View, CA

**Analytical Chemist**, 1986 – 1987

Syntex Research Inc., Palo Alto, CA

### HONORS AND AWARDS

**A. v. Humboldt Award** for Experienced Researchers. “*Excited State Dynamics of dsFP483, a Cyan Fluorescent Protein from Discosoma*”, 2008

**NIH National Research Service Award**, 1997 – 2000

**NIH Molecular Biology Training Grant**, 1992 – 1996

Eli Lilly & Co. Ph.D. Travel Award, 1994

Phi Beta Kappa, 1986

Honors in Major, Biochemistry and Molecular Biology, UC Santa Cruz, 1986

Honors in Senior Comprehensive Requirement, UC Santa Cruz, 1986

Crown College Honors, UC Santa Cruz, 1986

Henkel Scholarship, UC Santa Cruz, 1984-1986

### PATENTS

Wachter, Rebekka M.; Remington, S. James, 2003

*US Patent No. 6,593,135*: Long Wavelength Engineered Fluorescent Proteins.

Tsien, Roger Y.; Remington, S. James; Wachter, Rebekka M., 2000

*US Patent No. 6,150,176*: Fluorescent Protein Sensors for Measuring the pH of a Biological Sample.

### PROFESSIONAL AFFILIATIONS

Elected Member, American Society for Biochemistry and Molecular Biology

Member, International Society for Photosynthesis Research

Member, Biophysical Society

Member, American Society for Photobiology

Member, American Association for the Advancement of Science

Member, The Protein Society

### RESEARCH INTERESTS

**Protein Structure, Function and Dynamics:**

**X-ray Crystallography, Physical Biochemistry, Mechanistic Enzymology.**

- Regulation of Biological CO<sub>2</sub> Fixation: Rubisco Activase; Bioenergetics; Ring-forming ATPases; AAA+ Proteins; Chemo-Mechanical Motor Proteins; Supramolecular Assemblies; Predictive Modeling; Re-engineering Photosynthesis.
- Maturation of GFP-like Proteins: Chromophore Formation; Oxidative Self-Modification; Color Modulation; Photochromism; Photoconversion; Protein Evolution.

### PUBLICATIONS

50. Wachter, R.M. (2017) Photoconvertible Fluorescent Proteins and the Role of Dynamics in Protein Evolution. Perspective. *Int. J. Mol. Sci.* 18, 1792, doi:10.3390/ijms18081792.

49. Peterson-Forbrook, D., Hilton, M.T., Henderson, J.N., Tichacek, L., Bui, H.B., Wachter, R.M. (2017) Nucleotide Dependence of Subunit Rearrangements in Short-form Rubisco Activase from Spinach *Biochemistry* 56, 4906-4921 (doi: 10.1021/acs.biochem.7b00574).

48. Wachter, R.M. (2017) A Peptide Adhesive Molded by Magnesium Glues Rubisco's Subunits Together. *J. Biol. Chem.* 292, 6851-6852. doi:10.1074/jbc.H116.767145.

47. Doerner, K., Martin-Garcia, J.M., Kupitz, C., Gong, Z., Mallet, T.C., Chen, L., Wachter, R.M., Fromme, P. (2016) Characterization of Protein Nanocrystals Based on the Reversibility of Crystallization. *Cryst. Growth Des.* 16, 3838-3845.
46. Abdallah, B. G., Zatsepin, N. A., Roy-Chowdhury, S., Coe, J., Conrad, C. E., Dörner, K., Sierra, R. G., Stevenson, H. P., Camacho-Alanis, F., Grant, T. D., Nelson, G., James, D. R., Calero, G., Wachter, R. M., Spence, J. C. H., Weierstall, U., Fromme, P., Ros, A. (2015). XFEL Diffraction from Protein Nanocrystals Isolated Using a Microfluidic Sorter. *Structural Dynamics 2, Article No. 041719.*
45. Hazra, S., Henderson, J. N., Liles, K., Hilton, M., Wachter, R. M. (2015) Regulation of Rubisco Activase: Product Inhibition, Cooperativity, and Magnesium Activation. *J. Biol. Chem.* 290, 24222-24236 (epub 08/17/2015). **Selected to appear in a JBC special virtual issue on plant biology** <http://www.jbc.org/site/vi/plantbio/>.
44. Zook, J., Mo, G., Sisco, N., Craciunescu, F., Hansen, D., Baravati, B., Cherry, B., Wachter, R. M., Van Horn, W., Fromme, P. (2015). NMR Structure of *F. tularensis* Virulence Determinant Reveals Structural Homology to Bet v1 Allergen Proteins. *Structure* 23, 1116-1122.
43. Wachter, R. M. and Henderson, J. N. (2015) Rubisco Rescue. **News & Views, Nature Plants** 1, Article No. 14010 (epub January 8, 2015). DOI: 10.1038/NPLANTS.2014.10
42. Kim, H., Zou, T., Modi, C., Doerner, K., Grunkemeyer, T. J., Chen, L., Fromme, R., Matz, M. V., Ozkan\*, B., Wachter, R. M. (2015). A Hinge Migration Mechanism Unlocks the Evolution of Green-to-Red Photoconversion in GFP-like Proteins. *Structure* 23, 34-43 (epub 12/31/2014). **International Press Release.**
41. Kuriata, A. M., Chakraborty, M., Henderson, J. N., Hazra, S., Serban, A. J., Pham, T. V. T., Levitus, M., Wachter, R. M. (2014). ATP and Magnesium Promote Rubisco Activase Hexamer Formation at Low Micromolar Concentrations. *Biochemistry* 53, 7232–7246 (epub 10/30/2014).
40. Martin-Garcia, J., Hansen, D., Zook, J., Loskutov, A., Robida, M., Craciunescu, F., Sykes, K., Wachter, R. M., Fromme, P., Allen, J. P. (2014). Purification and Biophysical Characterization of the CapA Membrane Protein FTT0807 from *Francisella tularensis*. *Biochemistry* 53, 1958-1970.
39. Kim, H., Grunkemeyer, T. J., Modi, C., Chen, L., Fromme, R., Matz, M. V., Wachter, R. M. (2013), Acid-Base Catalysis and Crystal Structures of a Least-Evolved Ancestral GFP-like Protein Undergoing Green-to-Red Photoconversion. *Biochemistry* 52, 8048-8059. **Highlighted on the Journal's Home Page.**
38. Wachter, R. M., Salvucci, M. E., Carmo-Silva, A. E., Barta, C., Genkhov, T., Spreitzer, R. J. (2013), Activation of Interspecies-hybrid Rubisco Enzymes to Assess Different Models for the Rubisco – Rubisco Activase interaction. *Photosynth. Res.* 117, 557-566.
37. Kennis, J. T. M., van Stokkum, I. H. M., Peterson, D. S., Pandit, A., Wachter, R. M. (2013), Ultrafast Proton Shuttling in Psammocora Cyan Fluorescent Protein. *J. Phys. Chem. B* 117, 11134-11143.
36. Watkins, J. L., Kim, H., Markwardt, M. L., Chen, L., Fromme, R., Rizzo, M. A., Wachter, R. M. (2013) The 1.6 Å structure of a FRET-optimized Cerulean Fluorescent Protein. *Acta Crystallogr. D* 69, 767-773.
35. Henderson, J. N., Hazra, S., Dunkle, A. M., Salvucci, M. E., Wachter, R. M. (2013; epub 9/14/2012) Biophysical Characterization of Higher Plant Rubisco Activase. *Biophys. Biochim. Acta* 1834, 87-97.
34. Chakraborty, M., Kuriata, A. M., Henderson, J. N., Salvucci, M. E., Wachter, R. M., Levitus, M. (2012) Protein Oligomerization Monitored by Fluorescence Fluctuation Spectroscopy: Self-Assembly of Rubisco Activase. *Biophys. J.* 103, 949-958.
33. Henderson, J. N., Kuriata, A. M., Fromme, R., Salvucci, M. E., Wachter, R. M. (2011) Atomic Resolution X-ray Structure of the Substrate Recognition Domain of Higher Plant Rubisco Activase. *J. Biol. Chem.* 286, 35683-35688.
32. Markwardt, M. L., Kremers, G.-J., Kraft, C. A., Ray, K., Cranfill, P. J. C., Wilson, K. A., Day, R. N., Wachter, R. M., Davidson, M. W., Rizzo, M. A. (2011) An Improved Cerulean Fluorescent Protein with Enhanced Brightness and Reduced Reversible Photoswitching. *PlosOne* 6, e17896.
31. Wachter, R. M., Watkins, J. L., Kim, H. (2010) Mechanistic Diversity of Red Fluorescence Acquisition by GFP-like Proteins. *Biochemistry* 49, 7417-7427. **Current Topics Invited Review. Highlighted on the Journal's Home Page.**
30. Barta, C., Dunkle, A. M., Wachter, R. M., Salvucci, M. E. (2010) Structural Changes Associated with the Acute Thermal Instability of Rubisco Activase. *Arch. Biochem. Biophys.* 499, 17-25.

29. Pouwels, L. J., Zhang, L., Chan, N. H., Dorrestein, P. C., Wachter\*, R. M. (2008) Kinetic Isotope Effect Studies on the de novo Rate of Chromophore Formation in Fast- and Slow-maturing GFP Variants. *Biochemistry* 47, 10111-10122.
28. Malo, G. D., Wang, M., Wu, D., Stellin, A., Tonge, P. J., Wachter, R. M. (2008) Crystal Structure and Raman Studies of dsFP483, a Cyan Fluorescent Protein from *Discosoma striata*. *J. Mol. Biol.* 378, 869-884.
27. Malo, G. D., Pouwels, L. J., Wang, M., Weichsel, A., Montfort, W. R., Rizzo, M. A., Piston, D. W., Wachter, R. M. (2007). X-ray Structure of Cerulean GFP: A Tryptophan-Based Chromophore Useful for Fluorescence Lifetime Imaging. *Biochemistry* 46, 9865-9873. **Accelerated Publication. Featured as "Hot Article", Featured on the Journal's Most Accessed Articles Website.**
26. Wachter, R. M. (2007). Chromogenic Cross-link Formation in Green Fluorescent Protein. *Acc. Chem. Res.* 40, 120-127. **Invited Review.**
25. Zhang, L., Patel, H. N., Lappe, J. W., Wachter, R. M. (2006). Reaction Progress of Chromophore Biogenesis in Green Fluorescent Protein. *J. Am. Chem. Soc.* 128, 4766-4772.
24. Wachter, R. M. (2006). The family of GFP-like proteins: Structure, Function, Photophysics and Biosensor Applications. Introduction and Perspective, Symposium-in-print, *Photochem. Photobiol.* 82, 339-344. **Invited Review.**
23. Wachter, R. M. (2006). Mechanistic Aspects of GFP Chromophore Biogenesis. Progress in Biomedical Optics and Imaging 7. *Proc. of SPIE Vol. 6098, 609803-1 – 609803-8. Keynote Paper.*
22. Wang, M., Patel, H. N., Wachter, R. M. (2005). X-ray Diffraction Analysis and Molecular Replacement Solution of the Cyan Fluorescent Protein dsFP483. *Acta Crystallogr. F* 61, 922-924.
21. Sniegowski, J. A., Phail, M. E., Wachter, R. M. (2005). Maturation Efficiency, Trypsin Sensitivity and Optical Properties of Arg96, Glu222 and Gly67 Variants of Green Fluorescent Protein. *Biochem. Biophys. Res. Comm.* 332, 657-663.
20. Scruggs, A. W., Flores, C. L., Wachter, R. M., Woodbury, N. W. (2005). Development and Characterization of Green Fluorescent Protein Mutants with Altered Lifetimes. *Biochemistry* 44, 13377-13384.
19. Rosenow, M. A., Patel, H. N., Wachter, R. M. (2005). Oxidative Chemistry in the GFP Active Site Leads to Covalent Cross-Linking of a Modified Leucine Side Chain with a Histidine Imidazole: Implications for the Mechanism of Chromophore Formation. *Biochemistry* 44, 8303-8311.
18. Sniegowski, J. A., Lappe, J. W., Patel, H. N., Huffman, H. A., Wachter, R. M. (2005). Base-catalysis of Chromophore Formation in Arg96 and Glu222 variants of Green Fluorescent Protein. *J. Biol. Chem.* 280, 26248-26255.
17. Remington, S. J., Wachter, R. M., Yarbrough, D. K., Branchaud, B. P., Anderson, D. C., Kallio, K., Lukyanov, K. A. (2005). zFP538, a Yellow Fluorescent Protein from *Zoanthus*, Contains a Novel Three-Ring Chromophore. *Biochemistry* 44, 202-212. **"Top ten most cited", Year 2005.**
16. Rosenow, M. A., Huffman, H. A., Phail, M. E., Wachter, R. M. (2004). The Crystal Structure of the Y66L Variant of Green Fluorescent Protein Supports a Cyclization-Oxidation-Dehydration Mechanism for Chromophore Maturation. *Biochemistry* 43, 4464-4472.
15. Wachter, R. M. (2004). *Focus Note: The Art of Disentangling Difference Electron Density Maps: Snapshots of Early States in the Photoactive Yellow Protein Photocycle?* *Photochem. Photobiol.* 80, No.1, ix-x. **Invited Editorial.**
14. Bell, A. F., Stoner-Ma, D., Wachter, R. M., Tonge, P. J. (2003). Light Driven Decarboxylation of Wild-Type Green Fluorescent Protein. *J. Am. Chem. Soc.* 125, 6919-6926.
13. Yarbrough, D., Wachter, R. M., Kallio, K., Matz, M. V., Remington, S. J. (2001). Refined Crystal Structure of DsRed, a Red Fluorescent Protein from Coral, at 2.0 Å Resolution. *Proc. Natl. Acad. Sci. USA* 98, 462-467.
12. Wachter, R. M., Yarbrough, D., Kallio, K., Remington, S. J. (2000). Crystallographic and Energetic Analysis of Binding of Selected Anions to the Yellow Variants of Green Fluorescent Protein. *J. Mol. Biol.* 301, 159-173.
11. Bell, A. F., He, X., Wachter, R. M., Tonge, P. J. (2000). Probing the Ground State Structure of the Green Fluorescent Protein Chromophore Using Raman Spectroscopy. *Biochemistry* 39, 4423-4431.
10. Jayaraman, S., Haggie, P., Wachter, R. M., Remington, S. J., Verkman, A. S. (2000). Mechanism and Cellular Applications of a Green Fluorescent Protein-based Halide Sensor. *J. Biol. Chem.* 275, 6047-6050.

9. Wachter, R. M., Remington, S. J. (1999). Sensitivity of the YFP Form of Green Fluorescent Protein to Halides and Nitrate. *Curr. Biol.* 9, R628-R629.
8. Elsliger, M.-A., Wachter, R. M., Kallio, K., Hanson, G. T., Remington, S. J. (1999). Structural and Spectral Response of Green Fluorescent Protein Variants to Changes in pH. *Biochemistry* 38, 5296-5301.
7. Wachter, R. M., Elsliger, M.-A., Kallio, K., Hanson, G. T., Remington, S. J. (1998). Structural Basis of Spectral Shifts in the Yellow-emission Variants (YFPs) of Green Fluorescent Protein. *Structure* 6, 1267-1277.
6. Wachter, R. M., Branchaud, B. P. (1998). Construction and Analysis of a Semi-quantitative Energy Profile for the Reaction Catalyzed by the Radical Enzyme Galactose Oxidase. *Biochim. Biophys. Acta* 1384, 43-54.
5. Wachter, R. M., King, B. A., Heim, R., Kallio, K., Tsien, R. Y., Boxer, S. G., Remington, S. J. (1997). Crystal Structure and Photodynamic Behavior of the Blue-emission Variant Y66H/Y145F of Green Fluorescent Protein. *Biochemistry* 36, 9759-9765.
4. Wachter, R. M., Montague-Smith, M. P., Branchaud, B. P. (1997). Beta-Haloethanol Substrates as Probes for Radical Mechanisms for Galactose Oxidase. *J. Am. Chem. Soc.* 119, 7743-7749.
3. Wachter, R. M., Branchaud, B. P. (1996). Thiols as Mechanistic Probes for Catalysis by the Free Radical Enzyme Galactose Oxidase. *Biochemistry* 35, 14425-14435.
2. Wachter, R. M., Branchaud, B. P. (1996). Molecular Modeling Studies on Oxidation of Hexopyranoses by Galactose Oxidase. An Active Site Topology Apparently Designed to Catalyze Radical Reactions, Either Concerted or Stepwise. *J. Am. Chem. Soc.* 118, 2782-2789.
1. Montague-Smith, M. P., Wachter, R. M., Branchaud, B. P. (1992). Preparation of Fully Oxidized Active and Reduced Inactive Forms of Galactose Oxidase from *Dactylium dendroides* Using Ferricyanide-containing Oxidizing and Ferrocyanide-containing Reducing Forms of Ion Exchange Resins. *Anal. Biochem.* 207, 353-355.

#### EDITORIAL SERVICE

- Editorial Board Member, *The Journal of Biological Chemistry* (07/2013 – 09/2018).
- Editorial Board Member, *Biophysica et Biochimica Acta*, Proteins and Proteomics (02/2014 – 01/2017).
- Associate Editor, *Photochemistry and Photobiology* (2003 – 2007).
- Editor, *Genetically Engineered Probes for Biomedical Applications*, Progress in Biomedical Optics and Imaging, Vol. 7, No. 21 (2006)

#### Ph.D.s AWARDED

- *Dayna Peterson-Forbrook*. Thesis Title: Subunit Exchange in Spinach Short Form Rubisco Activase (April 2017).
- *Suratna Hazra*. Thesis Title: Enzyme Kinetic Analysis of Higher Plant Rubisco Activase. Ph.D. Biochemistry (April 2015).
- *Agnieszka Kuriata*. Thesis Title: Self-Assembly Mechanism of Rubisco Activase. Ph.D. Biochemistry (July 2014).
- *Jennifer L. Watkins*. Thesis Title: Structural and Functional Interrogation of Single Amino Acid Residues in Fluorescent Proteins. Ph.D Biochemistry (May 2012).
- *Hanseong Kim*. Thesis Title: Color Evolution of Kaede-type Red Fluorescent Proteins. Ph.D. Biochemistry (May 2012).
- *Wu, Di*. Thesis Title: Structural Studies on *M. tuberculosis* Protein Factors. Ph.D., Biochemistry (July 2009).
- *Sniegowski, Jennifer A*. Thesis Title: The Green Fluorescent Protein. Roles of Conserved Residues in Chromophore Maturation. Ph.D., Chemistry (May 2005).

#### MASTERS AWARDED

- *Laura Tichacek*. Research Thesis Title: Product Inhibition of Rubisco Activase (August 2016).
- *Matthew Hilton*. Master of Science, Molecular and Cellular Biology (May 2016).

- *Conrad, Alan*. Research Thesis Title: Limited Proteolysis of the AAA+ Protein Rubisco Activase from *Nicotiana tabacum* (May 2012).
- *Malo, Gabrielle D.* Research Thesis Title: X-ray Structures of Cyan Fluorescent Proteins (Dec. 2008).
- *Zhang, Liping*. Research Thesis Title: Kinetic Studies on the Maturation Mechanism of Green Fluorescent Protein (Dec. 2006).

#### POST-DOCTORAL ASSOCIATES SUPERVISED

- *Dörner, Katerina*. Project: Biophysical Characterization and Crystallization of Membrane Proteins. Ph.D. Albert-Ludwigs-University Freiburg, 2010. (Aug. 11 – Dec. 14). *Current Position*: Staff Research Associate, DESY (Deutsches Elektronen Synchrotron) CFEL (Center for Free-Electron Laser Science), Hamburg, Germany.
- *Henderson, Nathan J.* Project: Biophysical Studies on Rubisco Activase. Ph.D. University of Oregon, 2007 (Nov. 09 – Sept.16).
- *Gopalan, Gayathri* Ph.D. National University of Singapore, 2005. Project: Peptide Conformation in GFP (Sept. 05 - March 06).
- *Rosenow, Matthew A.* Ph.D. Arizona State University, 2003. Project: X-ray Crystallographic Studies on Variants of Green Fluorescent Protein (May 03 – May 05).
- *Huffman, Holly A.* Ph.D. University of California Riverside, 2000. Project: Chromophore Formation in Green Fluorescent Protein (01 – 02). *Current Position*: Senior Lecturer, ASU School of Letters and Sciences.

#### COURSES TAUGHT

BCH467	General Biochemistry Laboratory (Undergraduate)	Spring 2002, Spring 2003, Spring 2004, Fall 2004, Spring 2005
BCH563	Biophysical Chemistry (Graduate)	Fall 2002, Fall 2003
BCH598	Structural Biochemistry (Graduate)	Fall 2004, Spring 2006
BCH501	Current Topics in Biochemistry (Graduate)	Fall 2002, Fall 2003, Spring 2005, Spring 2006, Fall 2007, Spring 2007, Spring 2009, Spring 2010, Spring 2011
BCH598-CHM598	Chemical Biology (Graduate)	Fall 2006, Fall 2007, Fall 2008
BCH462	General Biochemistry II (Undergraduate)	Spring 2007, Fall 2008
BCH461	General Biochemistry I (Undergraduate)	Spring 2009, Fall 2009, Spring 2010, Spring 2011, Spring 2012
BCH598-CHM598	Special Topics (Graduate)	Fall 2009
BDE701-BCH598	Biological Design I (Graduate)	Fall 2010, Fall 2011
BCH465	Protein and Nucleic Acid Biochemistry (Undergraduate)	Fall 2011
BCH494	Proteins and Energy, Protein Biochemistry (Undergraduate)	Spring 2012, Fall 2012, Spring 2013, Fall 2013, Spring 2014, Fall 2014, Fall 2015, Fall 2016, Spring 2018
BCH463	Biophysical Chemistry	Fall 2012, Fall 2013, Spring 2014, Fall 2014, Fall 2015, Spring 2016, Spring 2017, Fall 2017
BCH561	Advanced Biochemistry (Graduate)	Spring 2013