Part III

APPENDIX

BIBLIOGRAPHY

[1] N. Nelson and C. F. Yocum. 'Structure and function of photosystem I and II.' *Annu Rev Plant Biol* 57.1 (2006), pp. 521–565 (cit. on p. 3).

[2] F. Rappaport, A. Boussac, D. A. Force, J. Peloquin, M. Brynda, M. Sugiura, S. Un, R. D. Britt, and B. A. Diner. 'Probing the coupling between proton and electron transfer in photosystem II core complexes containing a 3-fluorotyrosine.' *J Am Chem Soc* 131.12 (2009), pp. 4425–33 (cit. on p. 4).

[3] R. E. Blankenship. *Molecular mechanisms of photosynthesis, 2nd edition*. Wiley-Blackwell, 2014 (cit. on pp. 4, 24, 50, 82).

[4] X. Wei, X. Su, P. Cao, X. Liu, W. Chang, M. Li, X. Zhang, and Z. Liu. 'Structure of spinach photosystem II–LHCII supercomplex at 3.2 Å resolution.' *Nature* 534.7605 (2016), pp. 69–74 (cit. on pp. 4, 109).

[5] Z. Liu, H. Yan, K. Wang, T. Kuang, J. Zhang, L. Gui, X. An, and W. Chang. 'Crystal structure of spinach major light-harvesting complex at 2.72 A resolution.' *Nature* 428.6980 (2004), pp. 287–292 (cit. on pp. 4, 5, 25, 50, 82, 86).

[6] E. J. Boekema, B. Hankamer, D. Bald, J. Kruip, J. Nield, A. F. Boonstra, J. Barber, and M. Rogner. 'Supramolecular structure of the photosystem II complex from green plants and cyanobacteria.' *Proc Natl Acad Sci U S A* 92.1 (1995), pp. 175–179 (cit. on pp. 5, 109).

[7] X. Pan, M. Li, T. Wan, L. Wang, C. Jia, Z. Hou, X. Zhao, J. Zhang, and W. Chang. 'Structural insights into energy regulation of light-harvesting complex CP29 from spinach.' *Nat Struct Mol Biol* 18.3 (2011), pp. 309–15 (cit. on p. 5).

[8] R. Kouřil, J. P. Dekker, and E. J. Boekema. 'Supramolecular organization of photosystem II in green plants.' *Biochim Biophys Acta* 1817.1 (2012), pp. 2–12 (cit. on pp. 5, 109).

[9] J. P. Dekker and E. J. Boekema. 'Supramolecular organization of thylakoid membrane proteins in green plants.' *Biochim Biophys Acta* 1706.1-2 (2005), pp. 12–39 (cit. on pp. 5, 24).

[10] S. Caffarri, R. Kouril, S. Kereïche, E. J. Boekema, and R. Croce. 'Functional architecture of higher plant photosystem II supercomplexes.' *EMBO J* 28.19 (2009), pp. 3052–63 (cit. on pp. 5, 109, 110).

[11] H. Scheer. 'An overview of chlorophylls and bacteriochlorophylls: biochemistry, biophysics, functions and applications.' *Chlorophylls and bacteriochlorophylls*. 2006, pp. 1–26 (cit. on p. 6).

[12] H. Kramer and P. Mathis. 'Quantum yield and rate of formation of the carotenoid triplet state in photosynthetic structures.' *Biochim Biophys Acta* 593.2 (1980), p. 319 (cit. on pp. 6, 25, 44, 52, 109).

[13] A. J. Young. 'The photoprotective role of carotenoids in higher plants.' *Physiol Plant* 83.4 (1991), pp. 702–708 (cit. on p. 6).

[14] E. J. Peterman, F. M. Dukker, R. van Grondelle, and H. van Amerongen. 'Chlorophyll a and carotenoid triplet states in light-harvesting complex II of higher plants.' *Biophys J* 69.6 (1995), pp. 2670–2678 (cit. on pp. 6, 25, 31, 34, 43).

[15] V. Barzda, E. J. G. Peterman, R. van Grondelle, and H. van Amerongen. 'The influence of aggregation on triplet formation in light-harvesting chlorophyll a/b pigment-protein complex II of green plants.' *Biochemistry* 37.2 (1998), pp. 546–551 (cit. on pp. 6, 25, 43).

[16] R. van Grondelle, J. P. Dekker, T. Gillbro, and V. Sundstrom. 'Energy transfer and trapping in photosynthesis.' *Biochim Biophys Acta* 1187.1 (1994), pp. 1–65 (cit. on pp. 6, 8, 24, 50, 82, 109, 124).

[17] G. S. Beddard and G. Porter. 'Concentration quenching in chlorophyll.' *Nature* 260.5549 (1976), pp. 366–367 (cit. on p. 7).

[18] H. van Amerongen, L. Valkunas, and R. van Grondelle. *Photosynthetic Excitons*. Singapore: World Scientific, 2000, p. 590 (cit. on pp. 7, 24, 109).

[19] V. Novoderezhkin, A. Marin, and R. van Grondelle. 'Intra-and inter-monomeric transfers in the light harvesting LHCII complex: the Redfield–Förster picture.' *Phys Chem Chem Phys* 13.38 (2011), pp. 17093–17103 (cit. on pp. 7, 31, 82, 85, 94).

[20] S. Caffarri, K. Broess, R. Croce, H. van Amerongen, and H. van Amerongen. 'Excitation energy transfer and trapping in higher plant photosystem II complexes with different antenna sizes.' *Biophys J* 100.9 (2011), pp. 2094–2103 (cit. on pp. 7, 83, 109, 114).

[21] D. A. Berthold, G. T. Babcock, and C. F. Yocum. 'A highly resolved, oxygen-evolving photosystem II preparation from spinach thylakoid membranes.' *FEBS Lett* 134.2 (1981), pp. 231–234 (cit. on p. 7).

[22] K. Broess, G. Trinkunas, C. D. van der Weij-de Wit, J. P. Dekker, A. van Hoek, and H. van Amerongen. 'Excitation energy transfer and charge separation in photosystem II membranes revisited.' *Biophys J* 91.10 (2006), pp. 3776–3786 (cit. on pp. 7, 109, 114, 122, 125, 126).

[23] E. C. M. Engelmann, G. Zucchelli, F. M. Garlaschi, A. P. Casazza, and R. C. Jennings. 'The effect of outer antenna complexes on the photochemical trapping rate in barley thylakoid Photosystem II.' *Biochim Biophys Acta* 1706.3 (2005), pp. 276–286 (cit. on p. 7).

[24] T. A. Roelofs, C. H. Lee, and A. R. Holzwarth. 'Global target analysis of picosecond chlorophyll fluorescence kinetics from pea chloroplasts: A new approach to the characterization of the primary processes in photosystem II alpha- and beta-units.' *Biophys J* 61.5 (1992), pp. 1147–1163 (cit. on p. 7).

[25] A. W. Rutherford, A. Osyczka, and F. Rappaport. 'Back-reactions, short-circuits, leaks and other energy wasteful reactions in biological electron transfer: Redox tuning to survive life in O2.' *FEBS Lett* 586.5 (2012), pp. 603–616 (cit. on p. 9).

[26] A. V. Ruban, M. P. Johnson, and C. D. P. Duffy. 'The photoprotective molecular switch in the photosystem II antenna.' *Biochim Biophys Acta* 1817.1 (2012), pp. 167–181 (cit. on pp. 10, 50, 64, 65, 82, 108, 109, 124).

[27] J. Zaks, K. Amarnath, E. J. Sylak-Glassman, and G. R. Fleming. 'Models and measurements of energy-dependent quenching.' *Photosynth Res* 116.2-3 (2013), pp. 389–409 (cit. on pp. 10, 108, 124).

[28] K. K. Niyogi and T. B. Truong. 'Evolution of flexible non-photochemical quenching mechanisms that regulate light harvesting in oxygenic photosynthesis.' *Curr Opin Plant Biol* 16.3 (2013), pp. 307–314 (cit. on pp. 10, 64, 82, 108, 124).

[29] K. Dietz. 'Efficient high light acclimation involves rapid processes at multiple mechanistic levels.' *J Exp Bot* 66.9 (2015), pp. 2401–2414 (cit. on p. 10).

[30] P. Horton, A. V. Ruban, and M. Wentworth. 'Allosteric regulation of the light-harvesting system of photosystem II.' *Philos Trans R Soc Lond B Biol Sci* 355.1402 (2000), pp. 1361–70 (cit. on p. 10).

[31] G. Bonente, B. D. Howes, S. Caffarri, G. Smulevich, and R. Bassi. 'Interactions between the photosystem II subunit PsbS and xanthophylls studied in vivo and in vitro.' *J Biol Chem* 283.13 (2008), pp. 8434–8445 (cit. on p. 10).

[32] L. Dall'Osto, S. Cazzaniga, M. Wada, and R. Bassi. 'On the origin of a slowly reversible fluorescence decay component in the Arabidopsis npq4 mutant.' *Philos Trans R Soc Lond B Biol Sci* 369.1640 (2014), p. 20130221 (cit. on p. 10).

[33] E. Bergantino, A. Segalla, A. Brunetta, E. Teardo, F. Rigoni, G. M. Giacometti, and I. Szabo. 'Light- and pH-dependent structural changes in the PsbS subunit of photosystem II.' *Proc Natl Acad Sci U S A* 100.25 (2003), pp. 15265–15270 (cit. on p. 10).

[34] P. Horton and A. Ruban. 'Molecular design of the photosystem II light-harvesting antenna: Photosynthesis and photoprotection.' *J Exp Bot* 56.411 (2005), pp. 365–373 (cit. on pp. 10, 50).

[35] M. P. Johnson, T. K. Goral, C. D. P. Duffy, A. P. R. Brain, C. W. Mullineaux, and A. V. Ruban. 'Photoprotective energy dissipation involves the reorganization of photosystem II light-harvesting complexes in the grana membranes of spinach chloroplasts.' *Plant Cell* 23.April (2011), pp. 1468–1479 (cit. on p. 10).

[36] P. Horton, M. Wentworth, and A. Ruban. 'Control of the light harvesting function of chloroplast membranes: The LHCII-aggregation model for non-photochemical quenching.' *FEBS Lett* 579.20 (2005), pp. 4201–4206 (cit. on pp. 10, 65).

[37] A. V. Ruban, R. Berera, C. Ilioaia, I. H. M. van Stokkum, J. T. M. Kennis, A. a. Pascal, H. van Amerongen, B. Robert, P. Horton, and R. van Grondelle. 'Identification of a mechanism of photoprotective energy dissipation in higher plants.' *Nature* 450.7169 (2007), pp. 575–578 (cit. on pp. 11, 50, 60, 83, 109).

[38] C. D. P. Duffy and A. V. Ruban. 'Dissipative pathways in the photosystem-II antenna in plants.' *J Photochem Photobiol B* 152 (2015), pp. 215–226 (cit. on p. 11).

[39] Q. Wang, R. H. Goldsmith, Y. Jiang, S. D. Bockenhauer, and W. E. Moerner. 'Probing single biomolecules in solution using the anti-brownian electrokinetic (ABEL) trap.' *Acc Chem Res* 45.11 (2012), pp. 1955–1964 (cit. on p. 12).

[40] C. Hofmann, T. J. Aartsma, H. Michel, and J. Kohler. 'Direct observation of tiers in the energy landscape of a chromoprotein: a single-molecule study.' *Proc Natl Acad Sci U S A* 100.26 (2003), pp. 15534–15538 (cit. on pp. 12, 43).

[41] F. Cichos, C. von Borczyskowski, and M. Orrit. 'Power-law intermittency of single emitters.' *Curr Opin Colloid Interface Sci* 12.6 (2007), pp. 272–284 (cit. on p. 14).

[42] A. L. Efros and D. J. Nesbitt. 'Origin and control of blinking in quantum dots.' *Nat Nano* 11.8 (2016), pp. 661–671 (cit. on p. 14).

[43] R. B. Altman, D. S. Terry, Z. Zhou, Q. Zheng, P. Geggier, R. A. Kolster, Y. Zhao, J. A. Javitch, J. D. Warren, and S. C. Blanchard. 'Cyanine fluorophore derivatives with enhanced photostability.' *Nat Methods* 9.1 (2011), pp. 68–71 (cit. on p. 14).

[44] J. H. M. van der Velde et al. 'Intramolecular photostabilization via triplet-state quenching: design principles to make organic fluorophores "self-healing".' *Faraday Discuss* 184 (2015), pp. 221–235 (cit. on p. 14).

[45] W. E. Moerner. 'Single-molecule spectroscopy, Imaging, and photocontrol: Foundations for super-resolution microscopy (Nobel lecture).' *Angew Chem Int Ed Engl* 54.28 (2015), pp. 8067–8093 (cit. on p. 14).

[46] T. P. J. Krüger, C. Ilioaia, L. Valkunas, and R. van Grondelle. 'Fluorescence Intermittency from the Main Plant Light-Harvesting Complex: Sensitivity to the Local Environment.' *J Phys Chem B* 115.18 (2011), pp. 5083–5095 (cit. on pp. 14, 26, 31, 40, 121, 122, 127).

[47] T. P. J. Krüger, V. I. Novoderezkhin, C. Ilioaia, and R. van Grondelle. 'Fluorescence spectral dynamics of single LHCII trimers.' *Biophys J* 98.12 (2010), pp. 3093–3101 (cit. on pp. 14, 27, 43, 51, 54, 61, 83, 84, 89, 93, 110, 127).

[48] T. P. J. Krüger, E. Wientjes, R. Croce, and R. van Grondelle. 'Conformational switching explains the intrinsic multifunctionality of plant light-harvesting complexes.' *Proc Natl Acad Sci U S A* 108.33 (2011), pp. 13516–21 (cit. on pp. 14, 83).

[49] J. R. Lakowitz. *Principles of Fluorescence Spectroscopy*. Springer Science & Business Media, 2013, p. 698 (cit. on p. 15).

[50] B. van Oort, A. Amunts, J. W. Borst, A. van Hoek, N. Nelson, H. van Amerongen, and R. Croce. 'Picosecond fluorescence of intact and dissolved PSI-LHCI crystals.' *Biophys J* 95.12 (2008), pp. 5851–5861 (cit. on pp. 16, 78).

[51] C. Tredwell and C. Keary. 'Picosecond time resolved fluorescence lifetimes of the polymethine and related dyes.' *Chem Phys* 43.3 (1979), pp. 307–316 (cit. on p. 16).

[52] H. van Amerongen and R. van Grondelle. 'Understanding the energy transfer function of LHCII, the major light-harvesting complex of green plants.' *J Phys Chem B* 105.3 (2001), pp. 604–617 (cit. on pp. 24, 25, 82).

[53] R. Croce and H. van Amerongen. 'Light-harvesting and structural organization of photosystem II: from individual complexes to thylakoid membrane.' *J Photochem Photobiol B* 104.1-2 (2011), pp. 142–153 (cit. on pp. 24, 82).

[54] R. J. Cogdell and H. A. Frank. 'How carotenoids function in photosynthetic bacteria.' *Biochim Biophys Acta* 895.2 (1987), pp. 63–79 (cit. on p. 25).

[55] J. Breton, N. E. Geacintov, and C. E. Swenberg. 'Quenching of fluorescence by triplet excited states in chloroplasts.' *Biochim Biophys Acta* 548.3 (1979), pp. 616–635 (cit. on p. 25).

[56] H. J. den Blanken, A. J. Hoff, A. P. J. M. Jongenelis, and B. A. Diner. 'High-resolution triplet-minus-singlet absorbance difference spectrum of photosystem II particles.' *FEBS Lett* 157.1 (1983), pp. 21–27 (cit. on p. 25).

[57] K. Apel and H. Hirt. 'Reactive oxygen species: metabolism, oxidative stress, and signal transduction.' *Annu Rev Plant Biol* 55.1 (2004), pp. 373–399 (cit. on p. 25).

[58] D. Siefermann-Harms. 'The light-harvesting and protective functions of carotenoids in photosynthetic membranes.' *Physiol Plant* 69.3 (1987), pp. 561–568 (cit. on pp. 25, 109).

[59] V. I. Novoderezhkin, M. A. Palacios, H. van Amerongen, and R. van Grondelle. 'Excitation dynamics in the LHCII complex of higher plants: modeling based on the 2.72 Å crystal structure.' *J Phys Chem B* 109.20 (2005), pp. 10493–10504 (cit. on pp. 25, 82, 83, 85, 88, 92, 94).

[60] G. S. Schlau-Cohen, T. R. Calhoun, N. S. Ginsberg, E. L. Read, M. Ballottari, R. Bassi, R. van Grondelle, and G. R. Fleming. 'Pathways of energy flow in LHCII from two-dimensional electronic spectroscopy.' *J Phys Chem B* 113.46 (2009), pp. 15352–15363 (cit. on pp. 25, 83, 88, 92).

[61] C. D. P. Duffy, J. Chmeliov, M. Macernis, J. Sulskus, L. Valkunas, and A. V. Ruban. 'Modeling of fluorescence quenching by lutein in the plant light-harvesting complex LHCII.' *J Phys Chem B* 117.38 (2013), pp. 10974–86 (cit. on pp. 25, 60, 83, 109).

[62] J. Chmeliov, W. P. Bricker, C. Lo, E. Jouin, L. Valkunas, A. V. Ruban, and C. D. P. Duffy. 'An 'all pigment' model of excitation quenching in LHCII.' *Phys Chem Chem Phys* 17.24 (2015), pp. 15857–15867 (cit. on pp. 25, 109, 122, 126).

[63] P. G. Bowers and G. Porter. 'Quantum yields of triplet formation in solutions of chlorophyll.' *Proc R Soc Lond A Math Phys Sci* 296.1447 (1967), pp. 435–441 (cit. on pp. 25, 43).

[64] W. Kuhlbrandt, D. N. Wang, and Y. Fujiyoshi. 'Atomic model of plant light-harvesting complex by electron crystallography.' *Nature* 367.6464 (1994), pp. 614–621 (cit. on pp. 25, 83).

[65] M. Mozzo, L. Dall'Osto, R. Hienerwadel, R. Bassi, and R. Croce. 'Photoprotection in the antenna complexes of photosystem II Role of individual xanthophylls in chlorophyll triplet quenching.' *J Biol Chem* 283.10 (2008), pp. 6184–6192 (cit. on p. 25).

[66] R. Croce, R. Remelli, C. Varotto, J. Breton, and R. Bassi. 'The neoxanthin binding site of the major light harvesting complex (LHCII) from higher plants.' *FEBS Lett* 456.1 (1999), pp. 1–6 (cit. on p. 25).

[67] S. Caffarri, R. Croce, J. Breton, and R. Bassi. 'The major antenna complex of photosystem II has a xanthophyll binding site not involved in light harvesting.' *J Biol Chem* 276.38 (2001), pp. 35924–35933 (cit. on p. 25).

[68] L. Valkunas, V. Liuolia, and A. Freiberg. 'Picosecond processes in chromatophores at various excitation intensities.' *Photosynth Res* 27.2 (1991), pp. 83–95 (cit. on pp. 25, 112).

[69] G. Paillotin, C. E. Swenberg, J. Breton, and N. E. Geacintov. 'Analysis of picosecond laser induced fluorescence phenomena in photosynthetic membranes utilizing a master equation approach.' *Biophys J* 25.3 (1979), pp. 513–533 (cit. on pp. 25, 36).

[70] R. van Grondelle. 'Excitation energy transfer, trapping and annihilation in photosynthetic systems.' *Biochim Biophys Acta* 811.2 (1985), pp. 147–195 (cit. on pp. 25, 36).

[71] L. Valkunas, G. Trinkunas, V. Liuolia, and R. van Grondelle. 'Nonlinear annihilation of excitations in photosynthetic systems.' *Biophys J* 69.3 (1995), pp. 1117–29 (cit. on pp. 25, 124).

[72] T. Kolubayev, N. E. Geacintov, G. Paillotin, and J. Breton. 'Domain sizes in chloroplasts and chlorophyll-protein complexes probed by fluorescence yield quenching induced by singlet-triplet exciton annihilation.' *Biochim Biophys Acta* 808.1 (1985), pp. 66–76 (cit. on p. 25).

[73] F. Steiner. 'Singlet-triplet annihilation limits exciton yield in poly (3-hexylthiophene).' *Phys Rev Lett* 112.13 (2014), p. 137402 (cit. on p. 26).

[74] Y. Zaushitsyn, K. G. Jespersen, L. Valkunas, V. Sundström, and A. Yartsev. 'Ultrafast dynamics of singlet-singlet and singlet-triplet exciton annihilation in poly(3-2'-methoxy-5'octylphenyl)thiophene films.' *Phys Rev B* 75.19 (2007), p. 195201 (cit. on pp. 26, 31, 34, 35).

[75] V. Barzda, V. Gulbinas, R. Kananavicius, V. Cervinskas, H. van Amerongen, R. van Grondelle, and L. Valkunas. 'Singlet-singlet annihilation kinetics in aggregates and trimers of LHCII.' *Biophys J* 80.5 (2001), pp. 2409–2421 (cit. on pp. 26, 31, 36, 112, 125).

[76] D. Rutkauskas, J. Chmeliov, M. Johnson, A. Ruban, and L. Valkunas. 'Exciton annihilation as a probe of the light-harvesting antenna transition into the photoprotective mode.' *Chem Phys* 404 (2012), pp. 123–128 (cit. on pp. 26, 36, 112, 125).

[77] T. J. Pflock, S. Oellerich, J. Southall, R. J. Cogdell, G. M. Ullmann, and J. Köhler. 'The electronically excited states of LH2 complexes from rhodopseudomonas acidophila strain 10050 studied by time-resolved spectroscopy and dynamic Monte Carlo simulations. I. Isolated, non-interacting LH2 complexes.' *J Phys Chem B* 115.28 (2011), pp. 8813–8820 (cit. on p. 26).

[78] G. S. Schlau-Cohen, H.-Y. Yang, T. P. J. Krüger, P. Xu, M. Gwizdala, R. van Grondelle, R. Croce, and W. E. Moerner. 'Single-molecule identification of quenched andunquenched states of LHCII.' *J Phys Chem Lett* 6 (2015), pp. 860–867 (cit. on pp. 26, 58, 60, 109, 127).

[79] W. E. Moerner and M. Orrit. 'Illuminating single molecules in condensed matter.' *Science* 283.5408 (1999), pp. 1670–1676 (cit. on p. 26).

[80] H. van Roon, J. F. L. van Breemen, F. L. De Weerd, J. P. Dekker, and E. J. Boekema. 'Solubilization of green plant thylakoid membranes with n-dodecyl-α,D-maltoside. Implications for the structural organization of the Photosystem II, Photosystem I, ATP synthase and cytochrome b6f complexes.' *Photosynth Res* 64.2-3 (2000), pp. 155–166 (cit. on pp. 26, 51).

[81] C. E. Aitken, R. A. Marshall, and J. D. Puglisi. 'An oxygen scavenging system for improvement of dye stability in single-molecule fluorescence experiments.' *Biophys J* 94.5 (2008), pp. 1826–35 (cit. on p. 27).

[82] D. Rutkauskas, V. Novoderezkhin, R. J. Cogdell, and R. van Grondelle. 'Fluorescence spectral fluctuations of single LH2 complexes from Rhodopseudomonas acidophila strain 10050.' *Biochemistry* 43.15 (2004), pp. 4431–4438 (cit. on pp. 27, 84).

[83] T. P. J. Krüger, C. Ilioaia, and R. van Grondelle. 'Fluorescence Intermittency from the Main Plant Light-Harvesting Complex: Resolving Shifts between Intensity Levels.' *J Phys Chem B* 115.18 (2011), pp. 5071–5082 (cit. on pp. 27, 40, 43, 52, 61, 111, 122).

[84] R. W. K. Leung, S.-C. A. Yeh, and Q. Fang. 'Effects of incomplete decay in fluorescence lifetime estimation.' *Biomed Opt Express* 2.9 (2011), pp. 2517–2531 (cit. on p. 28).

[85] H. M. Visser, F. J. Kleima, I. H. M. van Stokkum, R. van Grondelle, and H. van Amerongen. 'Probing the many energy-transfer processes in the photosynthetic light-harvesting complex II at 77 K using energy-selective sub-picosecond transient absorption spectroscopy.' *Chem Phys* 210.1-2 (1996), pp. 297–312 (cit. on p. 31).

[86] L. Valkunas, I. H. van Stokkum, R. Berera, and R. van Grondelle. 'Exciton migration and fluorescence quenching in LHCII aggregates: Target analysis using a simple nonlinear annihilation scheme.' *Chem Phys* 357.1-3 (2009), pp. 17–20 (cit. on p. 31).

[87] R. Schödel, K. D. Irrgang, J. Voigt, and G. Renger. 'Quenching of chlorophyll fluorescence by triplets in solubilized light-harvesting complex II (LHCII).' *Biophys J* 76.4 (1999), pp. 2238–2248 (cit. on pp. 31, 34, 43).

[88] M. Pope and C. E. Swenberg. *Electronic Processes in Organic Crystals and Polymers*. 2nd. Monographs on the Physics and Chemistry of Materials. New York: Oxford University Press, 1999, xxix, 1328 p. (Cit. on p. 35).

[89] J. G. C. Bakker, R. van Grondelle, and W. T. F. den Hollander. 'Trapping, loss and annihilation of excitations in a photosynthetic system: II. Experiments with the purple bacteria Rhodospirillum rubrum and Rhodopseudomonas capsulata.' *Biochim Biophys Acta* 725.3 (1983), pp. 508–518 (cit. on p. 36).

[90] L. Valkunas, V. Cervinskas, and F. van Mourik. 'Energy transfer and connectivity in chloroplasts: Competition between trapping and annihilation in pulsed fluorescence induction experiments.' *J Phys Chem B* 101.37 (1997), pp. 7327–7331 (cit. on p. 36).

[91] M. W. Graham, J. Chmeliov, Y.-Z. Ma, H. Shinohara, A. A. Green, M. C. Hersam, L. Valkunas, and G. R. Fleming. 'Exciton dynamics in semiconducting carbon Nanotubes.' *J Phys Chem B* 115.18 (2011), pp. 5201–5211 (cit. on pp. 36, 112, 125).

[92] I. Moya, M. Silvestri, O. Vallon, G. Cinque, and R. Bassi. 'Time-resolved fluorescence analysis of the photosystem II antenna proteins in detergent micelles and liposomes.' *Biochemistry* 40.42 (2001), pp. 12552–12561 (cit. on pp. 40, 58, 60, 66, 75).

[93] Y. Miloslavina, A. Wehner, P. H. Lambrev, E. Wientjes, M. Reus, G. Garab, R. Croce, and A. R. Holzwarth. 'Far-red fluorescence: A direct spectroscopic marker for LHCII oligomer formation in non-photochemical quenching.' *FEBS Lett* 582.25-26 (2008), pp. 3625–3631 (cit. on p. 40).

[94] J. Chmeliov, G. Trinkunas, H. van Amerongen, and L. Valkunas. 'Light harvesting in a fluctuating antenna.' *J Am Chem Soc* 136.25 (2014), pp. 8963–8972 (cit. on pp. 42, 109, 122, 126).

[95] L. Valkunas, E. Akesson, T. Pullerits, and V. Sundstrom. 'Energy migration in the light-harvesting antenna of the photosynthetic bacterium Rhodospirillum rubrum studied by time-resolved excitation annihilation at 77 K.' *Biophys J* 70.5 (1996), pp. 2373–2379 (cit. on p. 42).

[96] R. Croce and H. van Amerongen. 'Natural strategies for photosynthetic light harvesting.' *Nat Chem Biol* 10.7 (2014), pp. 492–501 (cit. on pp. 50, 64, 82).

[97] J. F. Allen. 'Protein phosphorylation in regulation of photosynthesis.' *Biochim Biophys Acta* 1098.3 (1992), pp. 275–335 (cit. on p. 50).

[98] R. Kouril, A. Zygadlo, A. A. Arteni, C. D. de Wit, J. P. Dekker, P. E. Jensen, H. V. Scheller, and E. J. Boekema. 'Structural characterization of a complex of photosystem I and light-harvesting complex II of Arabidopsis thaliana.' *Biochemistry* 44.33 (2005), pp. 10935–40 (cit. on p. 50).

[99] A. V. Ruban, P. J. Lee, M. Wentworth, A. J. Young, and P. Horton. 'Determination of the stoichiometry and strength of binding of xanthophylls to the photosystem II light harvesting complexes.' *J Biol Chem* 274.15 (1999), pp. 10458–10465 (cit. on p. 50).

[100] J. Standfuss, A. C. Terwisscha van Scheltinga, M. Lamborghini, and W. Kühlbrandt. 'Mechanisms of photoprotection and nonphotochemical quenching in pea light-harvesting complex at 2.5 A resolution.' *EMBO J* 24.5 (2005), pp. 919–928 (cit. on pp. 50, 82).

[101] D. Reinsberg, P. J. Booth, C. Jegerschöld, B. J. Khoo, and H. Paulsen. 'Folding, assembly, and stability of the major light-harvesting complex of higher plants, LHCII, in the presence of native lipids.' *Biochemistry* 39.46 (2000), pp. 14305–14313 (cit. on p. 50).

[102] S. Scheidelaar, M. C. Koorengevel, J. D. Pardo, J. D. Meeldijk, E. Breukink, and J. A. Killian. 'Molecular model for the solubilization of membranes into nanodisks by styrene maleic acid copolymers.' *Biophys J* 108.2 (2015), pp. 279–290 (cit. on p. 50).

[103] D. J. K. Swainsbury, S. Scheidelaar, R. van Grondelle, J. A. Killian, and M. R. Jones. 'Bacterial reaction centers purified with styrene maleic acid copolymer retain native membrane functional properties and display enhanced stability.' *Angew Chem Int Ed Engl* 53.44 (2014), pp. 11803–7 (cit. on pp. 50, 61).

[104] J. M. Dörr, S. Scheidelaar, M. C. Koorengevel, J. J. Dominguez, M. Schäfer, C. A. van Walree, and J. A. Killian. 'The styrene-maleic acid copolymer: a versatile tool in membrane research.' *Eur Biophys J* 45.1 (2015), pp. 3–21 (cit. on p. 50).

[105] K. Yasushi. 'New trends in photobiology.' *J Photochem Photobiol B* 9.3-4 (1991), pp. 265–280 (cit. on p. 51).

[106] J. M. Gruber, J. Chmeliov, T. P. J. Krüger, L. Valkunas, and R. van Grondelle. 'Singlet - triplet annihilation in single LHCII complexes.' *Phys Chem Chem Phys* 17.30 (2015), pp. 19844–19853 (cit. on pp. 51–53, 55, 58, 79, 112, 115, 122, 125, 126).

[107] T. P. J. Krüger. *From disorder to order: The functional flexibility of single plant light-harvesting complexes*. Amsterdam: Vrije Universiteit, 2011 (cit. on p. 53).

[108] Y. Tian, J. Halle, M. Wojdyr, D. Sahoo, and I. G. Scheblykin. 'Quantitative measurement of fluorescence brightness of single molecules.' *Methods Appl Fluoresc* 2.3 (2014), p. 035003 (cit. on pp. 53, 114).

[109] M. A. Palacios, F. L. de Weerd, J. A. Ihalainen, R. van Grondelle, and H. van Amerongen. 'Superradiance and exciton (de) localization in light-harvesting complex II from green plants?' *J Phys Chem B* 106.22 (2002), pp. 5782–5787 (cit. on pp. 53, 82, 89).

[110] D. I. G. Bennett, K. Amarnath, and G. R. Fleming. 'A structure-based model of energy transfer reveals the principles of light harvesting in photosystem II supercomplexes.' *J Am Chem Soc* 135.24 (2013), pp. 9164–73 (cit. on pp. 53, 83, 109, 122, 126).

[111] B. van Oort, A. van Hoek, A. V. Ruban, and H. van Amerongen. 'Aggregation of Light-Harvesting Complex II leads to formation of efficient excitation energy traps in monomeric and trimeric complexes.' *FEBS Lett* 581.18 (2007), pp. 3528–3532 (cit. on p. 58).

[112] E. Iwaszko, A. Wardak, Z. Krupa, and W. I. Gruszecki. 'Ion transport across model lipid membranes containing light-harvesting complex II: an effect of light.' *J Photochem Photobiol B* 74.1 (2004), pp. 13–21 (cit. on pp. 60, 75).

[113] S. Schaller, D. Latowski, M. Jemiola-Rzeminska, C. Wilhelm, K. Strzalka, and R. Goss. 'The main thylakoid membrane lipid monogalactosyldiacylglycerol (MGDG) promotes the de-epoxidation of violaxanthin associated with the light-harvesting complex of photosystem II (LHCII).' *Biochim Biophys Acta* 1797.3 (2010), pp. 414–24 (cit. on p. 60).

[114] A. Pandit, N. Shirzad-Wasei, L. M. Wlodarczyk, H. van Roon, E. J. Boekema, J. P. Dekker, and W. J. De Grip. 'Assembly of the major light-harvesting complex II in lipid nanodiscs.' *Biophys J* 101.10 (2011), pp. 2507–2515 (cit. on pp. 60, 61).

[115] L. Tian, E. Dinc, and R. Croce. 'LHCII Populations in different quenching states are present in the thylakoid membranes in a ratio that depends on the light conditions.' *J Phys Chem Lett* 6.12 (2015), pp. 2339–2344 (cit. on pp. 60, 65).

[116] M. Y. Berezin and S. Achilefu. 'Fluorescence lifetime measurements and biological imaging.' *Chem Rev* 110.5 (2010), pp. 2641–84 (cit. on p. 60).

[117] B. van Oort, R. van Grondelle, and I. H. M. van Stokkum. 'A hidden state in Light-Harvesting Complex II revealed by multipulse spectroscopy.' *J Phys Chem B* 119.16 (2015), pp. 5184–93 (cit. on pp. 60, 109).

[118] T. P. Krüger, C. Ilioaia, M. P. Johnson, A. V. Ruban, E. Papagiannakis, P. Horton, and R. van Grondelle. 'Controlled disorder in plant light-harvesting complex II explains its photoprotective role.' *Biophys J* 102.11 (2012), pp. 2669–2676 (cit. on pp. 61, 109).

[119] S. Nußberger, K. Dörr, D. N. Wang, and W. Kühlbrandt. 'Lipid-protein interactions in crystals of plant light-harvesting complex.' *J Mol Biol* 234.2 (1993), pp. 347–356 (cit. on p. 61).

[120] N. Liguori, X. Periole, S. J. Marrink, and R. Croce. 'From light-harvesting to photoprotection: structural basis of the dynamic switch of the major antenna complex of plants (LHCII).' *Sci Rep* 5 (2015), p. 15661 (cit. on pp. 61, 109).

[121] A. M. Seddon, P. Curnow, and P. J. Booth. 'Membrane proteins, lipids and detergents: not just a soap opera.' *Biochim Biophys Acta* 1666.1-2 (2004), pp. 105–117 (cit. on p. 62).

[122] J.-D. Rochaix. 'Regulation and dynamics of the light-harvesting system.' *Annu Rev Plant Biol* 65 (2014), pp. 287–309 (cit. on p. 64).

[123] T. Roach and A. Krieger-Liszkay. 'Regulation of photosynthetic electron transport and photoinhibition.' *Curr Protein Pept Sci* 15 (2014), pp. 351–362 (cit. on p. 64).

[124] X. P. Li, O. Björkman, C. Shih, A. R. Grossman, M. Rosenquist, S. Jansson, and K. K. Niyogi. 'A pigment-binding protein essential for regulation of photosynthetic light harvesting.' *Nature* 403.6768 (2000), pp. 391–5 (cit. on p. 64).

[125] G. Peers, T. B. Truong, E. Ostendorf, A. Busch, D. Elrad, A. R. Grossman, M. Hippler, and K. K. Niyogi. 'An ancient light-harvesting protein is critical for the regulation of algal photosynthesis.' *Nature* 462.7272 (2009), pp. 518–21 (cit. on p. 64).

[126] P. Jahns, B. Depka, and A. Trebst. 'Xanthophyll cycle mutants from Chlamydomonas reinhardtii indicate a role for zeaxanthin in the D1 protein turnover.' *Plant Physiol Biochem* 38.5 (2000), pp. 371–376 (cit. on p. 65).

[127] P. Horton, A. V. Ruban, D. Rees, A. A. Pascal, G. Noctor, and A. J. Young. 'Control of the light-harvesting function of chloroplast membranes by aggregation of the LHCII chlorophyll-protein complex.' *FEBS Lett* 292.1-2 (1991), pp. 1–4 (cit. on pp. 65, 68).

[128] A. V. Ruban, D. Phillip, A. J. Young, and P. Horton. 'Carotenoid-dependent oligomerization of the major chlorophyll a/b light harvesting complex of photosystem II of plants.' *Biochemistry* 36.25 (1997), pp. 7855–7859 (cit. on p. 65).

[129] M. Wentworth, A. V. Ruban, and P. Horton. 'Chlorophyll fluorescence quenching in isolated light harvesting complexes induced by zeaxanthin.' *FEBS Lett* 471.1 (2000), pp. 71–74 (cit. on p. 65).

[130] R. Bassi and S. Caffarri. 'Lhc proteins and the regulation of photosynthetic light harvesting function by xanthophylls.' *Photosynth Res*. Vol. 64. 2-3. 2000, pp. 243–256 (cit. on p. 65).

[131] P. Jahns and A. R. Holzwarth. 'The role of the xanthophyll cycle and of lutein in photoprotection of photosystem II.' *Biochim Biophys Acta* 1817.1 (2012), pp. 182–193 (cit. on p. 65).

[132] E. Belgio, M. P. Johnson, S. Jurić, and A. V. Ruban. 'Higher plant photosystem II light-harvesting antenna, not the reaction center, determines the excited-state lifetime - Both the maximum and the nonphotochemically quenched.' *Biophys J* 102.June (2012), pp. 2761–2771 (cit. on pp. 65, 108, 127).

[133] J. Borch and T. Hamann. *The nanodisc: A novel tool for membrane protein studies*. 2009 (cit. on p. 65).

[134] A. J. Bell, L. K. Frankel, and T. M. Bricker. 'High yield non-detergent isolation of photosystem I-light-harvesting chlorophyll II membranes from spinach thylakoids: Implications for the organization of the PS I antennae in higher plants.' *J Biol Chem* 290.30 (2015), pp. 18429–18437 (cit. on p. 65).

[135] N. Liguori, L. M. Roy, M. Opacic, G. Durand, and R. Croce. 'Regulation of light harvesting in the green alga chlamydomonas reinhardtii: The c-terminus of lhcsr is the knob of a dimmer switch.' *J Am Chem Soc* 135.49 (2013), pp. 18339–18342 (cit. on p. 65).

[136] F. Zhou, S. Liu, Z. Hu, T. Kuang, H. Paulsen, and C. Yang. 'Effect of monogalactosyldiacylglycerol on the interaction between photosystem II core complex and its antenna complexes in liposomes of thylakoid lipids.' *Photosynth Res* 99.3 (2009), pp. 185–193 (cit. on pp. 65, 75).

[137] C. Yang, S. Boggasch, W. Haase, and H. Paulsen. 'Thermal stability of trimeric light-harvesting chlorophyll a/b complex (LHCIIb) in liposomes of thylakoid lipids.' *Biochim Biophys Acta* 1757.12 (2006), pp. 1642–1648 (cit. on pp. 65, 66, 75).

[138] A. Wardak, R. Brodowski, Z. Krupa, and W. I. Gruszecki. 'Effect of light-harvesting complex II on ion transport across model lipid membranes.' *J Photochem Photobiol B* 56.1 (2000), pp. 12–18 (cit. on p. 65).

[139] H. Kirchhoff, H.-J. Hinz, and J. Rösgen. 'Aggregation and fluorescence quenching of chlorophyll a of the light-harvesting complex II from spinach in vitro.' *Biochim Biophys Acta* 1606.1-3 (2003), pp. 105–16 (cit. on pp. 65, 68).

[140] L. Wilk, M. Grunwald, P.-N. Liao, P. J. Walla, and W. Kühlbrandt. 'Direct interaction of the major light-harvesting complex II and PsbS in nonphotochemical quenching.' *Proc Natl Acad Sci U S A* 110.14 (2013), pp. 5452–6 (cit. on pp. 65, 75).

[141] C. Liu, Z. Gao, K. Liu, R. Sun, C. Cui, A. R. Holzwarth, and C. Yang. 'Simultaneous refolding of denatured PsbS and reconstitution with LHCII into liposomes of thylakoid lipids.' *Photosynth Res* (2015) (cit. on pp. 65, 66, 75).

[142] A. Vieler, C. Wilhelm, R. Goss, R. Süß, and J. Schiller. 'The lipid composition of the unicellular green alga Chlamydomonas reinhardtii and the diatom Cyclotella meneghiniana investigated by MALDI-TOF MS and TLC.' *Chem Phys Lipids* 150.2 (2007), pp. 143–155 (cit. on pp. 66, 77).

[143] S. Georgakopoulou, G. van der Zwan, R. Bassi, R. van Grondelle, H. van Amerongen, and R. Croce. 'Understanding the changes in the circular dichroism of light harvesting complex II upon varying its pigment composition and organization.' *Biochemistry* 46.16 (2007), pp. 4745–4754 (cit. on pp. 66, 74, 83, 87, 88, 92–94).

[144] A. V. Ruban, F. Calkoen, S. L. S. Kwa, R. van Grondelle, P. Horton, and J. P. Dekker. 'Characterisation of LHC II in the aggregated state by linear and circular dichroism spectroscopy.' *Biochim Biophys Acta* 1321.1 (1997), pp. 61–70 (cit. on p. 68).

[145] B. Drop, M. Webber-Birungi, S. K. N. Yadav, A. Filipowicz-Szymanska, F. Fusetti, E. J. Boekema, and R. Croce. 'Light-harvesting complex II (LHCII) and its supramolecular organization in Chlamydomonas reinhardtii.' *Biochim Biophys Acta* 1837.1 (2014), pp. 63–72 (cit. on pp. 69, 77).

[146] A. Natali and R. Croce. 'Characterization of the major light-harvesting complexes (LHCBM) of the green alga Chlamydomonas reinhardtii.' *PLoS One* 10.2 (2015) (cit. on p. 69).

[147] S. Haferkamp and H. Kirchhoff. 'Significance of molecular crowding in grana membranes of higher plants for light harvesting by photosystem II.' *Photosynth Res*. Vol. 95. 2-3. 2008, pp. 129–134 (cit. on p. 75).

[148] R. Croce, S. Weiss, and R. Bassi. 'Carotenoid-binding sites of the major light-harvesting complex II of higher plants.' *Journal of Biological Chemistry* 274.42 (1999), pp. 29613–29623 (cit. on p. 75).

[149] S. Hobe, S. Prytulla, W. Kühlbrandt, and H. Paulsen. 'Trimerization and crystallization of reconstituted light-harvesting chlorophyll a/b complex.' *EMBO J* 13.15 (1994), pp. 3423–9 (cit. on p. 75).

[150] E. van Den Brink-Van Der Laan, J. Antoinette Killian, and B. De Kruijff. 'Non-bilayer lipids affect peripheral and integral membrane proteins via changes in the lateral pressure profile.' *Biochim Biophys Acta* 1666.1-2 (2004), pp. 275–288 (cit. on p. 75).

[151] U. Armbruster et al. 'Arabidopsis curvature thylakoid1 proteins modify thylakoid architecture by inducing membrane curvature.' *Plant Cell* 25.7 (2013), pp. 2661–78 (cit. on p. 76).

[152] M. Suorsa, M. Rantala, F. Mamedov, M. Lespinasse, A. Trotta, M. Grieco, E. Vuorio, M. Tikkanen, S. Järvi, and E. M. Aro. 'Light acclimation involves dynamic re-organization of the pigment-protein megacomplexes in non-appressed thylakoid domains.' *Plant J* 84.2 (2015), pp. 360–373 (cit. on p. 76).

[153] S. Puthiyaveetil, O. Tsabari, T. Lowry, S. Lenhert, R. R. Lewis, Z. Reich, and H. Kirchhoff. 'Compartmentalization of the protein repair machinery in photosynthetic membranes.' *Proc Natl Acad Sci U S A* 111.44 (2014), pp. 15839–15844 (cit. on p. 76).

[154] L. W. Bielczynski, G. Schansker, and R. Croce. 'Effect of light acclimation on the organization of photosystem II super- and sub-complexes in arabidopsis thaliana.' *Front Plant Sci* 7 (2016), p. 105 (cit. on p. 76).

[155] T. P. J. Krüger, C. Ilioaia, M. P. Johnson, A. V. Ruban, and R. van Grondelle. 'Disentangling the low-energy states of the major light-harvesting complex of plants and their role in photoprotection.' *Biochim Biophys Acta* 1837.7 (2014), pp. 1027–1038 (cit. on pp. 76, 83).

[156] D. S. Gorman and R. P. Levine. 'Cytochrome f and plastocyanin: their sequence in the photosynthetic electron transport chain of Chlamydomonas reinhardi.' *Proc Natl Acad Sci U S A* 54 (1965), pp. 1665–1669 (cit. on p. 76).

[157] N. Fischer, P. Sétif, and J. D. Rochaix. 'Targeted mutations in the psaC gene of Chlamydomonas reinhardtii: Preferential reduction of F(B) at low temperature is not accompanied by altered electron flow from photosystem I to ferredoxin.' *Biochemistry* 36.1 (1997), pp. 93–102 (cit. on p. 76).

[158] B. Drop, M. Webber-Birungi, F. Fusetti, R. Kouril, K. E. Redding, E. J. Boekema, and R. Croce. 'Photosystem I of Chlamydomonas reinhardtii contains nine light-harvesting complexes (Lhca) located on one side of the core.' *J Biol Chem* 286.52 (2011), pp. 44878–44887 (cit. on p. 76).

[159] A. Natali, L. M. Roy, and R. Croce. 'In vitro reconstitution of light-harvesting complexes of plants and green algae.' *J Vis Exp* 92 (2014), e51852 (cit. on pp. 77, 84, 92).

[160] K. Gundermann and C. Büchel. 'Factors determining the fluorescence yield of fucoxanthin-chlorophyll complexes (FCP) involved in non-photochemical quenching in diatoms.' *Biochim Biophys Acta* 1817.7 (2012), pp. 1044–1052 (cit. on p. 77).

[161] F. F. Rossetti, I. Reviakine, G. Csúcs, F. Assi, J. Vörös, and M. Textor. 'Interaction of poly(L-lysine)-g-poly(ethylene glycol) with supported phospholipid bilayers.' *Biophys J* 87.3 (2004), pp. 1711–21 (cit. on p. 79).

[162] K. Akashi, H. Miyata, H. Itoh, and K. Kinosita. 'Formation of giant liposomes promoted by divalent cations: critical role of electrostatic repulsion.' *Biophys J* 74.6 (1998), pp. 2973–2982 (cit. on p. 79).

[163] G. R. Fleming and R. van Grondelle. 'The primary steps of photosynthesis.' *Phys Today* 47.2 (1994), pp. 48–55 (cit. on p. 82).

[164] V. I. Novoderezhkin and R. van Grondelle. 'Physical origins and models of energy transfer in photosynthetic light-harvesting.' *Phys Chem Chem Phys* 12.27 (2010), pp. 7352–7365 (cit. on p. 82).

[165] R. van Grondelle and V. I. Novoderezhkin. 'Energy transfer in photosynthesis: experimental insights and quantitative models.' *Phys Chem Chem Phys* 8.7 (2006), pp. 793–807 (cit. on p. 82).

[166] P. Horton, A. V. Ruban, and R. G. Walters. 'Regulation of light harvesting in green plants.' *Annu Rev Plant Physiol Plant Mol Biol* 47.1 (1996), pp. 655–684 (cit. on pp. 82, 108).

[167] P. Muller, X. Li, and K. Niyogi. 'Non-photochemical quenching. A response to excess light energy.' *Plant Physiol* 125.4 (2001), pp. 1558–1566 (cit. on p. 82).

[168] J. Adolphs and T. Renger. 'How proteins trigger excitation energy transfer in the FMO complex of green sulfur bacteria.' *Biophys J* 91.8 (2006), pp. 2778–97 (cit. on p. 82).

[169] W. Kühlbrandt. 'Structure and function of the plant light-harvesting complex, LHC-II.' *Curr Opin Struct Biol* 4.4 (1994), pp. 519–528 (cit. on p. 82).

[170] M. Mozzo, F. Passarini, R. Bassi, H. van Amerongen, and R. Croce. 'Photoprotection in higher plants: The putative quenching site is conserved in all outer light-harvesting complexes of Photosystem II.' *Biochim Biophys Acta* 1777.10 (2008), pp. 1263–1267 (cit. on pp. 82, 87, 88, 92).

[171] R. Remelli, C. Varotto, D. Sandonà, R. Croce, R. Bassi, D. Sandona, R. Croce, and R. Bassi. 'Chlorophyll binding to monomeric light-harvesting complex. A mutation analysis of chromophore-binding residues.' *J Biol Chem* 274.47 (1999), pp. 33510–33521 (cit. on pp. 82, 83, 87–89, 92).

[172] H. Rogl, R. Schödel, H. Lokstein, W. Kühlbrandt, and A. Schubert. 'Assignment of spectral substructures to pigment-binding sites in higher plant light-harvesting complex LHC-II.' *Biochemistry* 41.7 (2002), pp. 2281–2287 (cit. on pp. 82, 83, 92).

[173] C. Yang, K. Kosemund, C. Cornet, and H. Paulsen. 'Exchange of pigment-binding amino acids in light-harvesting chlorophyll a/b protein.' *Biochemistry* 38.49 (1999), pp. 16205–16213 (cit. on p. 82).

[174] T. Bittner, K.-D. Irrgang, G. Renger, and M. R. Wasielewski. 'Ultrafast excitation energy transfer and exciton. Exciton annihilation processes in isolated light harvesting complexes of photosystem II (LHC II) from spinach.' *J Phys Chem* 98.46 (1994), pp. 11821–11826 (cit. on p. 82).

[175] T. R. Calhoun, N. S. Ginsberg, G. S. Schlau-Cohen, Y.-C. Cheng, M. Ballottari, R. Bassi, and G. R. Fleming. 'Quantum coherence enabled determination of the energy landscape in light-harvesting complex II.' *J Phys Chem B* 113.51 (2009), pp. 16291–16295 (cit. on p. 82).

[176] M. Fuciman, M. M. Enriquez, T. Polívka, L. Dall'Osto, R. Bassi, and H. A. Frank. 'Role of xanthophylls in light harvesting in green plants: a spectroscopic investigation of mutant LHCII and Lhcb pigment–protein complexes.' *J Phys Chem B* 116.12 (2012), pp. 3834–3849 (cit. on p. 82).

[177] C. C. Gradinaru, S. Özdemir, D. Gülen, I. H. M. van Stokkum, R. van Grondelle, and H. van Amerongen. 'The flow of excitation energy in LHCII monomers: implications for the structural model of the major plant antenna.' *Biophys J* 75.6 (1998), pp. 3064–3077 (cit. on p. 82).

[178] F. J. Kleima, C. C. Gradinaru, F. Calkoen, I. H. M. van Stokkum, R. van Grondelle, and H. van Amerongen. 'Energy transfer in LHCII monomers at 77K studied by sub-picosecond transient absorption spectroscopy.' *Biochemistry* 36.49 (1997), pp. 15262–15268 (cit. on p. 82).

[179] F. Muh, M. E. A. Madjet, and T. Renger. 'Structure-based identification of energy sinks in plant light-harvesting complex II.' *J Phys Chem B* 114.42 (2010), pp. 13517–13535 (cit. on pp. 82, 88).

[180] F. Müh and T. Renger. 'Refined structure-based simulation of plant light-harvesting complex II: Linear optical spectra of trimers and aggregates.' *Biochim Biophys Acta* 1817.8 (2012), pp. 1446–1460 (cit. on p. 82).

[181] T. Renger, M. Madjet, A. Knorr, and F. Müh. 'How the molecular structure determines the flow of excitation energy in plant light-harvesting complex II.' *J Plant Physiol* 168.12 (2011), pp. 1497–1509 (cit. on p. 82).

[182] H. Rogl and W. Kühlbrandt. 'Mutant trimers of light-harvesting complex II exhibit altered pigment content and spectroscopic features.' *Biochemistry* 38.49 (1999), pp. 16214–16222 (cit. on pp. 82, 83, 88, 89, 92).

[183] M. Wentworth, A. V. Ruban, and P. Horton. 'Thermodynamic investigation into the mechanism of the chlorophyll fluorescence quenching in isolated photosystem II light-harvesting complexes.' *J Biol Chem* 278.24 (2003), pp. 21845–50 (cit. on p. 83).

[184] L. Valkunas, J. Chmeliov, T. P. J. Krüger, C. Ilioaia, and R. van Grondelle. 'How photosynthetic proteins switch.' *J Phys Chem Lett* 3.19 (2012), pp. 2779–2784 (cit. on p. 83).

[185] L. Valkunas, D. Abramavicius, and T. Mancal. *Molecular excitation dynamics and relaxation: quantum theory and spectroscopy*. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2013, pp. 1–449 (cit. on pp. 83, 86).

[186] S. Caffarri, F. Passarini, R. Bassi, and R. Croce. 'A specific binding site for neoxanthin in the monomeric antenna proteins CP26 and CP29 of Photosystem II.' *FEBS Lett* 581.24 (2007), pp. 4704–10 (cit. on p. 84).

[187] R. Croce, G. Canino, F. Ros, and R. Bassi. 'Chromophore organization in the higher-plant photosystem II antenna protein CP26.' *Biochemistry* 41.23 (2002), pp. 7334–7343 (cit. on p. 84).

[188] A. Chenu, P. Malý, and T. Mančal. 'Dynamic coherence in excitonic molecular complexes under various excitation conditions.' *Chem Phys* 439 (2014), pp. 100–110 (cit. on p. 85).

[189] T. Renger and R. A. Marcus. 'On the relation of protein dynamics and exciton relaxation in pigment-protein complexes: An estimation of the spectral density and a theory for the calculation of optical spectra.' *J Chem Phys* 116.22 (2002), pp. 9997–10019 (cit. on p. 86).

[190] V. Novoderezhkin, J. M. Salverda, H. van Amerongen, and R. van Grondelle. 'Exciton modeling of energy-transfer dynamics in the LHCII complex of higher plants: A redfield theory approach.' *J Phys Chem B* 107.8 (2003), pp. 1893–1912 (cit. on p. 87).

[191] V. I. Novoderezhkin, M. A. Palacios, H. van Amerongen, and R. Van Grondelle. 'Energy-transfer dynamics in the LHCII complex of higher plants: Modified redfield approach.' *J Phys Chem B* 108.29 (2004), pp. 10363–10375 (cit. on p. 87).

[192] E. J. G. Peterman, S. Hobe, F. Calkoen, R. van Grondelle, H. Paulsen, and H. Van Amerongen. 'Low-temperature spectroscopy of monomeric and trimeric forms of reconstituted light-harvesting chlorophyll a/b complex.' *Biochim Biophys Acta* 1273.2 (1996), pp. 171–174 (cit. on p. 89).

[193] F. G. Plumley and G. W. Schmidt. 'Reconstitution of chlorophyll a/b light-harvesting complexes: Xanthophyll-dependent assembly and energy transfer.' *Proc Natl Acad Sci U S A* 84.1 (1987), pp. 146–150 (cit. on p. 92).

[194] F. Passarini, P. Xu, S. Caffarri, J. Hille, and R. Croce. 'Towards in vivo mutation analysis: knock-out of specific chlorophylls bound to the light-harvesting complexes of Arabidopsis thaliana - the case of CP24 (Lhcb6).' *Biochim Biophys Acta* 1837.9 (2014), pp. 1500–1506 (cit. on pp. 93, 110).

[195] M. Brecht, M. Hussels, E. Schlodder, and N. V. Karapetyan. 'Red antenna states of Photosystem I trimers from Arthrospira platensis revealed by single-molecule spectroscopy.' *Biochim Biophys Acta* 1817.3 (2012), pp. 445–452 (cit. on p. 93).

[196] R. Kunz, K. Timpmann, J. Southall, R. J. Cogdell, A. Freiberg, and J. Köhler. 'Fluctuations in the electron-phonon coupling of a single chromoprotein.' *Angew Chem Int Ed Engl* 52.33 (2013), pp. 8726–30 (cit. on p. 93).

[197] G. H. Krause and E. Weis. 'Chlorophyll fluorescence and photosynthesis: the basics.' *Annu Rev Plant Physiol Plant Mol Biol* 42.1 (1991), pp. 313–349 (cit. on p. 108).

[198] N. R. Baker. 'Chlorophyll fluorescence: a probe of photosynthesis in vivo.' *Annu Rev Plant Biol* 59 (2008), pp. 89–113 (cit. on p. 108).

[199] M. Bradbury and N. R. Baker. 'Analysis of the slow phases of the in vivo chlorophyll fluorescence induction curve. Changes in the redox state of photosystem II electron acceptors and fluorescence emission from photosystems I and II.' *Biochim Biophys Acta* 635.3 (1981), pp. 542–551 (cit. on p. 108).

[200] J. Chmeliov, G. Trinkunas, H. van Amerongen, and L. Valkunas. 'Excitation migration in fluctuating light-harvesting antenna systems.' *Photosynth Res* 127.1 (2016), pp. 49–60 (cit. on pp. 109, 122, 126).

[201] J. Chmeliov, A. Gelzinis, E. Songaila, R. Augulis, C. D. P. Duffy, A. V. Ruban, and L. Valkunas. 'The nature of self-regulation in photosynthetic light-harvesting antenna.' *Nat Plants* (2016), p. 16045 (cit. on pp. 109, 122, 124, 126, 127).

[202] J. M. Gruber, S. Scheidelaar, H. van Roon, J. P. Dekker, J. A. Killian, and R. van Grondelle. 'Photophysics in single light-harvesting complexes II: from micelle to native nanodisks.' *SPIE BiOS*. Ed. by J. Enderlein, I. Gregor, Z. K. Gryczynski, R. Erdmann, and F. Koberling. International Society for Optics and Photonics, 2016, 97140A (cit. on pp. 109, 114, 117, 121).

[203] P. Xu, L. Tian, M. Kloz, and R. Croce. 'Molecular insights into Zeaxanthin-dependent quenching in higher plants.' *Sci Rep* 5 (2015), p. 13679 (cit. on p. 110).

[204] R. Bassi and P. Dainese. 'A supramolecular light-harvesting complex from chloroplast photosystem-II membranes.' *FEBS J* 204.1 (1992), pp. 317–326 (cit. on p. 114).

[205] F. van Mieghem, K. Brettel, B. Hillmann, A. Kamlowski, A. W. Rutherford, and E. Schlodder. 'Charge recombination reactions in photosystem II. I. Yields, recombination pathways, and kinetics of the primary pair.' *Biochemistry* 34.14 (1995), pp. 4798–4813 (cit. on pp. 117, 120, 121).

[206] F. J. E. van Mieghem, G. F. W. Searle, A. W. Rutherford, and T. J. Schaafsma. 'The influence of the double reduction of QA on the fluorescence decay kinetics of Photosystem II.' *Biochim Biophys Acta* 1100.2 (1992), pp. 198–206 (cit. on p. 120).

[207] I. Vass and S. Styring. 'Characterization of chlorophyll triplet promoting states in photosystem II sequentially induced during photoinhibition.' *Biochemistry* 32.13 (1993), pp. 3334–3341 (cit. on p. 120).

[208] I. Vass, G. Gatzen, and A. R. Holzwarth. 'Picosecond time-resolved fluorescence studies on photoinhibition and double reduction of QA in photosystem II.' *Biochim Biophys Acta* 1183.2 (1993), pp. 388–396 (cit. on p. 120).

[209] I. Vass, S. Styring, T. Hundal, A. Koivuniemi, E. Aro, and B. Andersson. 'Reversible and irreversible intermediates during photoinhibition of photosystem II: stable reduced QA species promote chlorophyll triplet formation.' *Proc Natl Acad Sci U S A* 89.4 (1992), pp. 1408–1412 (cit. on p. 120).

[210] S. B. Powles. 'Photoinhibition of photosynthesis induced by visible light.' *Annu Rev Plant Physiol* 35.1 (1984), pp. 15–44 (cit. on p. 120).

[211] I. Vass and K. Cser. 'Janus-faced charge recombinations in photosystem II photoinhibition.' *Trends Plant Sci* 14.4 (2009), pp. 200–205 (cit. on p. 120).

[212] V. Martínez-Junza, M. Szczepaniak, S. E. Braslavsky, J. Sander, M. M. Nowaczyk, M. Rögner, and A. R. Holzwarth. 'A photoprotection mechanism involving the D2 branch in photosystem II cores with closed reaction centers.' *Photochem Photobiol Sci* 7.11 (2008), pp. 1337–1343 (cit. on p. 121).

[213] L. Valkunas, G. Trinkunas, J. Chmeliov, and A. V. Ruban. 'Modeling of exciton quenching in photosystem II.' *Phys Chem Chem Phys* 11.35 (2009), pp. 7576–7584 (cit. on pp. 122, 125, 126).

[214] N. P. Pawlowicz, M.-L. Groot, I. H. M. van Stokkum, J. Breton, and R. van Grondelle. 'Charge separation and energy transfer in the photosystem II core complex studied by femtosecond midinfrared spectroscopy.' *Biophys J* 93.8 (2007), pp. 2732–42 (cit. on p. 124).

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[1] E. Cohen, M. Gruber, E. Romero, S. Yochelis, R. van Grondelle, and Y. Paltiel. 'Properties of self-assembled hybrid organic molecule/quantum dot multilayered structures.' *J Phys Chem C* 118.44 (2014), pp. 25725–25730.

[2] J. M. Gruber, J. Chmeliov, T. P. J. Krüger, L. Valkunas, and R. van Grondelle. 'Singlet - triplet annihilation in single LHCII complexes.' *Phys Chem Chem Phys* 17.30 (2015), pp. 19844–19853.

[3] C. Ramanan, J. M. Gruber, P. Malý, M. Negretti, V. Novoderezhkin, T. P. J. Krüger, T. Mančal, R. Croce, and R. van Grondelle. 'The role of exciton delocalization in the major photosynthetic light-harvesting antenna of plants.' *Biophys J* 108.5 (2015), pp. 1047–1056.

[4] V. M. Friebe, J. D. Delgado, D. J. K. Swainsbury, J. M. Gruber, A. Chanaewa, R. van Grondelle, E. von Hauff, D. Millo, M. R. Jones, and R. N. Frese. 'Plasmon-enhanced photocurrent of photosynthetic pigment proteins on nanoporous silver.' *Adv Funct Mater* 26.2 (2016), pp. 285–292.

[5] J. M. Gruber, S. Scheidelaar, H. van Roon, J. P. Dekker, J. A. Killian, and R. van Grondelle. 'Photophysics in single light-harvesting complexes II: from micelle to native nanodisks.' *SPIE BiOS*. Ed. by J. Enderlein, I. Gregor, Z. K. Gryczynski, R. Erdmann, and F. Koberling. International Society for Optics and Photonics, 2016, 97140A.

[6] J. M. Gruber, P. Xu, J. Chmeliov, T. P. J. Krüger, M. T. A. Alexandre, L. Valkunas, R. Croce, and R. van Grondelle. 'Dynamic quenching in single photosystem II supercomplexes.' *Phys Chem Chem Phys* 42 (2016), pp. 313–349.

[7] P. Malý, J. M. Gruber, R. J. Cogdell, T. Mančal, and R. van Grondelle. 'Ultrafast energy relaxation in single light-harvesting complexes.' *Proc Natl Acad Sci U S A* 113.11 (2016), pp. 2934–2939.

[8] P. Malý, J. M. Gruber, R. van Grondelle, and T. Mančal. 'Single molecule spectroscopy of monomeric LHCII: Experiment and theory.' *Sci Rep* 6 (2016), p. 26230.

[9] A. Natali, J. M. Gruber, L. Dietzel, M. C. A. Stuart, R. van Grondelle, and R. Croce. 'Light-harvesting complexes (LHC) cluster spontaneously in membrane environment leading to shortening of their excited state lifetimes.' *J Biol Chem* jbc.M116.7 (2016), jbc.M116.730101.

ACRONYMS

β-DM	n-Dodecyl β-D-maltoside
AOM	Acousto-optic modulator
ATP	Adenosin triphospate
BBY	Photosystem II membrane preparation [Berthold et al. (1981)]
Car	Carotenoid
CD	Circular dichroism
CFD	Constant fraction discriminator
Chl	Chlorophyll
CT	Charge transfer
Cyt b_6f	Cytochrome b_6f
EET	Excitation energy transfer
Fd	Ferredoxin
FWHM	Full width at half maximum
IC	Internal conversion
IRF	Instrument response function
ISC	Intersystem crossing
LHC	Light-harvesting complex
LHCII	Light-harvesting complex II
Lut	Lutein
NADPH	Reduced form of $NADP^+$
$NADP^+$	Nicotinamide adenine dinucleotide phosphate
NPQ	Non-photochemical quenching

OEC	Oxygen-evolving complex
PC	Plastocyanin
PSI	Photosystem I
PSII	Photosystem II
RC	Reaction center
RT	Room temperature
RMS	Root mean square
ROS	Reactive oxygen species
S-S	Singlet-singlet annihilation
S-T	Singlet-triplet annihilation
SI	Supporting information
SMS	Single-molecule spectroscopy
SNR	Signal-to-noise ratio
SPAD	Single-photon avalanche diode
TCSPC	Time correlated single photon counting
TTTR	Time-tagged time-resolved
TDC	Time to digital converter
Tyr_Z	Tyrosine-Z