

Literature overview: super-resolution microscopy in the far-field

[No aim to be complete]

Overview papers

- S.W. Hell. Towards fluorescence nanoscopy. *Nature Biotechnology*, 21(11):1347-1355, 2003.
- S.W. Hell. Far-field optical nanoscopy. *Science*, 316:1153-1158, 2007.
- S.W. Hell. Microscopy and its focal switch. *Nature Methods*, 6:24-32, 2009.
- R. Heintzmann and M.G.L. Gustafsson. Subdiffraction resolution in continuous samples. *Nature Photonics*, 3:362-364, 2009.
- J. Lippincott-Schwartz and S. Manley. Putting super-resolution fluorescence microscopy to work. *Nature Methods*, 6(1):21, 2009.
- L. Schermelleh, R. Heintzmann, and H. Leonhardt. A guide to super-resolution fluorescence microscopy. *The Journal of Cell Biology*, 190(2):165-175, 2010.
- A. Fuerstenberg and M. Heilemann. Single-molecule localization microscopy - near-molecular spatial resolution in light microscopy with photoswitchable fluorophores. *Physical Chemistry Chemical Physics*, 15(36):14919-14930, 2013.
- P. Sengupta, S. van Engelenburg, and J. Lippincott-Schwartz. Visualizing cell structure and function with point-localization superresolution imaging. *Developmental Cell*, 23(6):1092-1102, 2012.
- D. Kamiyama and B. Huang. Development in the storm. *Developmental Cell*, 23(6):1103-1110, 2012.
- T. Klein, S. Proppert, and M. Sauer. Eight years of single-molecule localization microscopy. *Histochem Cell Biology*, 141(6):561-575, 2014. DOI 10.1007/s00418-014-1184-3.

Technical landmark papers

- S.W. Hell and J. Wichmann. Breaking the diffraction limit resolution by stimulated emission: stimulated-emission-depletion microscopy. *Optics Letters*, 19(11):780-783, 1994.
- E. Betzig, G.H. Patterson, R. Sougrat, O.W. Lindwasser, S. Olenych, J.S. Bonifacino, M.W. Davidson, J. Lippincott-Schwartz, and H.F. Hess. Imaging intracellular fluorescent proteins at nanometer resolution. *Science*, 313:1643-1645, 2006.
- M.J. Rust, M. Bates, and X.W. Zhuang. Sub-diffraction-limit imaging by stochastic optical reconstruction microscopy (STORM). *Nature Methods*, 3(10):793-795, 2006.
- M. Heilemann, S. van de Linde, M. Schüttelz, R. Kasper, B. Seefeldt, A. Mukherjee, P. Tinnefeld, and M. Sauer. Subdiffraction-resolution fluorescence imaging with conventional fluorescent probes. *Angewandte Chemie*, 47(33):6172-6176, 2008.
- S.T. Hess, T.P.K. Girirajan, and M.D. Mason. Ultra-high resolution imaging by fluorescence photoactivation localization microscopy. *Biophysical Journal*, 91(11):4258-4272, 2006.
- R.J. Ober, S. Ram, and S.E. Ward. Localization accuracy in single-molecule microscopy. *Biophysical Journal*, 86(2):1185-1200, 2004.
- K.A. Lidke, B. Rieger, T.M. Jovin, and R. Heintzmann. Superresolution by localization of quantum dots using blinking statistics. *Optics Express*, 13(18):7052-7062, 2005.
- M.G.L. Gustafsson. Surpassing the lateral resolution limit by a factor of two using structured illumination microscopy. *Journal of Microscopy*, 198(2):82-87, 2000.

Application landmark papers

- K. Xu, G. Zhong, and X. Zhuang. Actin, spectrin, and associated proteins form a periodic cytoskeletal structure in axons. *Science*, 339:452-456, 2013.
- C. Eggeling, C. Ringemann, R. Medda, G. Schwarzmann, K. Sandhoff, S. Polyakova, V.N. Belov, B. Hein, C. von Middendorff, A. Schönle, and S. W. Hell. Direct observation of the nanoscale dynamics of membrane lipids in a living cell. *Nature*, 457:1159-1163, 2009.
- A. Szymborska, N. Marco, A de. Daigle, V.C. Cordes, J.A.G. Briggs, and J. Elllenberg. Nuclear pore scaffold structure analyzed by super-resolution microscopy and particle averaging. *Science*, 341(6146):655-658, August 2013.
- S.B. van Engelenburg, G. Shtengel, P. Sengupta, K. Waki, M. Jarnik, S.D. Abian, E.O. Freed, H.F. Hess, and J. Lippincott-Schwartz. Distribution of ESCRT machinery at HIV assembly sites reveals virus scaffolding of ESCRT subunits. *Science*, 343(6171):653, 2014.

Extensions of the above ideas

- J. Fölling, M. Bossi, H. Bock, R. Medda, C.A. Wurm, B. Hein, S. Jacobs, C. Eggeling, and S.W. Hell. Fluorescence nanoscopy by ground-state depletion and single-molecule return. *Nature Methods*, 5:943-945, 2008.
- T. Dertinger, R. Colyer, G. Iyer, S. Weiss, and J. Enderlein. Fast, background-free, 3D super-resolution optical fluctuation imaging (SOFI). *Proceedings of the National Academy of Sciences USA*, 106(52):22287-22292, 2009.
- A. Chmyrov, J. Keller, T. Grotjohann, M. Ratz, E. d'Este, S. Jakobs, C. Eggeling, and S.W. Hell. Nanoscopy with more than 100,000 'doughnuts'. *Nature Methods*, 10(8):737-740, 2013.
- G.T. Dempsey, J.C. Vaughan, K.H. Chen, M. Bates, and X. Zhuang. Evaluation of fluorophores for optimal performance in localization-based super-resolution imaging. *Nature Methods*, 8(12):1027-1031, 2011.
- M. Hofmann, C. Eggeling, S. Jakobs, and S.W. Hell. Breaking the diffraction barrier in fluorescence microscopy at low light intensities by using reversibly photoswitchable proteins. *Proceedings of the National Academy of Sciences USA*, 102(49):17565-17569, 2005.
- A. Löschberger, S. van de Linde, M.C. Dabauvalle, B. Rieger, M. Heilemann, G. Krohne, and M. Sauer. Super-resolution imaging visualizes the eightfold symmetry of gp210 proteins around the nuclear pore complex and resolves the central channel with nanometer resolution. *Journal of Cell Sciences*, 125(3):570-575, 2012.
- C.B. Müller and J. Enderlein. Image scanning microscopy. *Physical Review Letters*, 104:198101, 2010.
- A.G. York, P. Chandris, D. Dalle Nogare, J. Head, P. Wawrzusin, R.S. Fischer, A. Chitnis, and H. Shroff. Instant super-resolution imaging in live cells and embryos via analog image processing. *Nature Methods*, 2013. doi:10.1038/nmeth.2687.
- S. Roth, C.J.R. Sheppard, K. Wicker, and R. Heintzmann. Optical photon reassignment microscopy (OPRA). *Optical nanoscopy*, 2:5, 2013. doi:10.1186/2192-2853-2-5.
- G.M.R. De Luca, R.M.P. Breedijk, R.A.J. Brandt, C.H.C. Zeelenberg, B.E. de Jong, W. Timmermanns, L.N. Azar, R.A. Hoebe, S. Stallinga, and E.M.M. Manders. Re-scan confocal microscopy: scanning twice for better resolution. *Biomedical Optical Express*, 4(11):2644-2656, 2013.
- H. Bock, C. Geisler, C. A. Wurm, C. von Middendorff, S. Jakobs, A. Schönle, A. Egner, S. W. Hell, and C. Eggeling. Two-color far-field fluorescence nanoscopy based on photoswitchable emitters. *Applied Physics B - Lasers and Optics*, 88(2):161-165, 2007.
- S. Bretschneider, C. Eggeling, and S.W. Hell. Breaking the diffraction barrier in fluorescence microscopy by optical shelving. *Physical Review Letters*, page 218103, 2007.
- T. Grotjohann, T. Testa, M. Leutenegger, H. Bock, N.T. Urban, F. Lavoie-Cardinal, K.I. Willig, C. Eggeling, and S.W. Hell. Diffraction-unlimited all-optical imaging and writing with a photochromic GFP. *Nature*, 478:204-208, 2011.

In particular about localization microscopy

- P. Annibale, S. Vanni, M. Scarselli, U. Rothlisberger, and A. Radenovic. Quantitative photo activated localization microscopy: Unraveling the effects of photoblinking. *PLoS ONE*, 6(7):e22678, 2011.
- S.-H. Lee, J.Y. Shin, A. Lee, and C. Bustamante. Counting single photoactivatable fluorescent molecules by photoactivated localization microscopy (PALM). *Proceedings of the National Academy of Sciences USA*, 109(43):17436-17441, 2012.
- A. Egner, C. Geisler, C. von Middendorff, H. Bock, D. Wenzel, R. Medda, M. Andresen, A.C. Stiel, S. Jakobs, C. Eggeling, A. Schönle, and S.W. Hell. Fluorescence nanoscopy in whole cells by asynchronous localization of photoswitching emitters. *Biophysical Journal*, 93(9):3285-3290, 2007.
- C. von Middendorff, A. Egner, C. Geisler, S.W. Hell, and A. Schönle. Isotropic 3D nanoscopy based on single emitter switching. *Optics Express*, 16(25):20774-20788, December 2008.
- E.A. Mukamel, H. Babcock, and X. Zhuang. Statistical deconvolution for superresolution fluorescence microscopy. *Biophysical Journal*, 102:2391-2400, 2012.
- R.J. Ober, Z. Lin, and Q. Zou. Calculations of the Fisher information matrix for multidimensional data sets. *IEEE Transactions on Signal Processing*, 51(10):2679-2691, 2003.
- S. Ram, E.S. Ward, and R.J. Ober. Beyond Rayleighs criterion: A resolution measure with application to single-molecule microscopy. *Proceedings of the National Academy of Sciences USA*, 103(12):4457-4462, 2006.
- R.P.J. Nieuwenhuizen, K.A. Lidke, M. Bates, D. Leyton Puig, D. Grünwald, S. Stallinga, and B. Rieger. Measuring image resolution in optical nanoscopy. *Nature Methods*, 10:557-562, 2013.
- J.E. Fitzgerald, J. Lu, and M.J. Schnitzer. Estimation theoretic measure of resolution for stochastic localization microscopy. *Physical Review Letters*, 109:048102, 2012.
- E.A. Mukamel and M.J. Schnitzer. Unified resolution bounds for conventional and stochastic localization fluorescence microscopy. *Physical Review Letters*, 109:168102, 2012.
- C.S. Smith, N. Joseph, B. Rieger, and K.A. Lidke. Fast, single-molecule localization that achieves theoretically minimum uncertainty. *Nature Methods*, 7(5):373-375, 2010.
- S. Stallinga and B. Rieger. Accuracy of the Gaussian point spread function model in 2D localization microscopy. *Optics Express*, 18(24):24461-24476, 2010.
- P. Annibale, S. Vanni, M. Scarelli, U. Rothlisberger, and A. Radenovic. Identification of clustering artifacts in photoactivated localization microscopy. *Nature Methods*, 8(7):527-528, 2011.

- G. Shtengel, J.A. Galbraith, C.G. Galbraith, J. Lippincott-Schwartz, J.M. Gillette, S. Manely, R. Sougrat, C.M. Waterman, P. Knachanawong, M.W. Davidson, R.D. Fetter, and H.F. Hess. Interferometric fluorescent super-resolution microscopy resolves 3d cellular ultrastructure. *Proceeding of the National Academy of Science USA*, 106(9):3125-3130, 2009.
- T. Grotjohann, I. Testa, M. Reuss, T. Brakemann, C. Eggeling, S.W. Hell, and S. Jakobs. rsEGFP2 enables fast RESOLFT nanoscopy of living cells. *eLIFE*, 1:e00248, 2012.
- B. Huang, W. Wang, M. Bates, and X. Zhuang. Three-dimensional super-resolution imaging by stochastic optical reconstruction microscopy. *Science*, 319:810-813, 2008.
- H. Shroff, C. G. Galbraith, J. A. Galbraith, and E. Betzig. Live-cell photoactivated localization microscopy of nanoscale adhesion dynamics. *Nature Methods*, 5(5):417-423, 2008.
- M. Bates, S.A. Jones, and X. Zhuang. Imaging: A Laboratory Manual, chapter Stochastic Optical Reconstruction Microscopy (STORM): a method for super-resolution fluorescence imaging. Cold Spring Harbor Laboratory Press, 2011. ISBN 978-0-879699-36-9.
- J.C. Vaughan, S. Jia, and X. Zhuang. Ultrabright photoactivatable fluorophores created by reductive caging. *Nature Methods*, 9(12):1181-1184, 2012.
- M.P. Backlund, M.D. Lew, A.S. Backer, S.J. Sahl, G. Grover, A. Agrawal, R. Piestun, and W.E. Moerner. Simultaneous, accurate measurement of the 3D position and orientation of single molecules. *Proceedings of the National Academy of Sciences USA*, 109(47):19087-19092, 2012.
- A. Barsic and R. Piestun. Super-resolution of dense nanoscale emitters beyond the diffraction limit using spatial and temporal information. *Applied Physics Letters*, 102:231103, 2013.
- F. Huang, T.M.P. Hartwich, F.E. Rivera-Molina, Y. Lin, C. Whitney, J.J. Long, P.D. Uchil, J.R. Myers, M.A. Baird, W. Mothes, M.W. Davidson, D. Toomre, and J. Bewersdorf. Video-rate nanoscopy using sCMOS camera-specific single-molecule localization algorithms. *Nature Methods*, 10(7):653-658, 2013.
- M.J. Mlodzianoski, M.F. Juette, G.L. Beane, and J. Bewersdorf. Experimental characterization of 3d localization techniques for particle-tracking and super-resolution microscopy. *Optics Express*, 17(10):8264-8277, 2009.
- M.J. Mlodzianoski, J.M. Schreiner, S.P. Callahan, K. Smolkova, A. Dlaskova, J. Santorova, P. Jezek, and J. Bewersdorf. Sample drift correction in 3d fluorescence photoactivation localization microscopy. *Optics Express*, 19(16):15009-15019, 2011.
- A. Pertsinidis, Y. Zhang, and S. Chu. Subnanometre single-molecule localization, registration and distance measurements. *Nature*, 466:647-651, 2010.
- S.R.P. Pavani and R. Piestun. Three dimensional tracking of fluorescent microparticles using a photon-limited double-helix response system. *Optics Express*, 16(26):22048-22057, 2008.
- J. Chao, S. Ram, E.S. Ward, and R.J. Ober. Ultrahigh accuracy imaging modality for super-localization microscopy. *Nature Methods*, 2013.

- J. Chao, E.S. Ward, and R.J. Ober. Fisher information matrix for branching processes with application to electron-multiplying charge-coupled devices. *Multidimensional System and Signal Processing*, 23:349-379, 2012.
- Y. Wong, Z. Lin, and R.J. Ober. Limit of the accuracy of parameter estimation for moving single molecules imaged by fluorescence microscopy. *IEEE Transactions on Signal Processing*, 59(3):895-911, 2011.