
CURRICULUM VITAE

Joachim Frank, Ph.D.
Professor, Department of Biochemistry and Molecular Biophysics,
Columbia University College of Physicians and Surgeons
Professor, Department of Biological Sciences, Columbia University
Professor, Department of Biomedical Sciences, SUNY Albany
Distinguished Professor, SUNY Albany
HHMI Investigator
Member, National Academy of Sciences
Fellow, American Academy of Arts and Sciences
Fellow, American Academy of Microbiology

PERSONAL DATA:

Born: 9/12/40

Birthplace: Weidenau/Sieg, Germany

Marital Status: Married, two children (3/31/72 and 3/10/85)

Nationality: German; US Immigration Visa 1975; since 1997 US Citizen.

A. Fields of Specialization

- (1) Application of electron microscopy and image analysis to the elucidation of three-dimensional structure and function of macromolecular assemblies and cell components.
- (2) The mechanism of protein synthesis.

B. Academic Training

1. Colleges and Universities:

Universität Freiburg, Freiburg im Breisgau, Germany	1960-1963
Universität München, Germany	1963-1967
Technische Hochschule München (Technical University of Munich)	1967-1970

2. Degrees:

Vor-Diplom (equivalent to B.S.), University of Freiburg, Germany	1963
Diplom (equivalent to Masters), University of Munich, Germany	1967
Dr. rer. nat. (equ. to Ph.D.), Technical University of Munich, Germany	1970

3. Dissertations:

1. Diplom dissertation, titled: “Untersuchung der Sekundärelektronen-Emission von Gold am Schmelzpunkt” – “Investigation of the secondary electron emission of gold at its melting temperature.” Sponsor: Prof. Walter Rollwagen, Department of Physics, University of Munich.
2. Ph.D. (Dr. rer. nat.) dissertation, entitled: “Untersuchungen von elektronenmikroskopischen Aufnahmen hoher Auflösung mit Bilddifferenz- und Rekonstruktionsverfahren” – (“*Investigation of high-resolution electron micrographs using image difference and reconstruction methods.*”) Sponsor: Prof. Walter Hoppe, Technical University of Munich
Publications of material in the Ph.D. dissertation:
 - a) W. Hoppe, R. Langer, J. Frank and A. Feltynowski. Bilddifferenzverfahren in der Elektronenmikroskopie. (*Image difference methods in electron microscopy*). *Naturwissenschaften* 56, 267-272 (1969).
 - b) J. Frank. Nachweis von Objektbewegungen im lichtoptischen Diffraktogramm von elektronenmikroskopischen Aufnahmen. (*Detection of object movements in the light-optical diffractogram of electron micrographs*). *Optik* 30, 171-180 (1969).
 - c) J. Frank. Observation of the relative phases of electron microscopic phase contrast zones with the aid of the optical diffractometer. *Optik* 35, 608-612 (1972).

4. Honors, Awards, and Fellowships received:

- 1963 Studienstiftung des Deutschen Volkes
- 1970 The Harkness Fellowship
- 1987 Fogarty Senior International Fellowship
- 1991 Chairman of the Gordon Conference on Three-dimensional Electron Microscopy of Macromolecules
- 1993 Elizabeth Roberts Cole Award of the Biophysical Society (jointly with David DeRosier)
- 1994 Humboldt Fellowship for Senior U.S. Scientists
- 1995 Annual Lecture and Outstanding Scientist Citation by the Max Gruber Foundation, Groningen, The Netherlands
- 1997 Elected Fellow of the American Association for the Advancement of Science.
- 1998 Howard Hughes Medical Institute Investigator Award; initial appointment 7 years, twice renewed for 5 years each.
- 2001 Recipient of the 2000-2001 University at Albany Award for Excellence in Research
- 2001 Distinguished Lecturer at the Twenty-ninth Peter A. Leermakers Symposium Wesleyan University.
- 2001 Elected Fellow of the Biophysical Society
- 2001 Scientific Merit Award, as “Scientist of the Fourth Quarter Century” by the New York State Department of Health
- 2003 Recognized as “Distinguished Scientist for Biological Sciences for 2003” by the Microscopy Society of America
- 2003 Chancellor’s Research Recognition Award from the University at Albany, SUNY
- 2005 National Lecturer of the Biophysical Society 2005 Annual Meeting
- 2006 Elected Fellow of the American Academy of Arts and Sciences
- 2006 Elected Member of the National Academy of Sciences
- 2006 Named Wadsworth Distinguished Scientist in Structural Biology
- 2006 Elected Fellow of the American Academy of Microbiology
- 2007 Appointed Distinguished Professor, State University of New York

- 2008 George E. Palade Distinguished Lecture and Gold Medal (with Ada Yonath and Thomas Steitz), Wayne State University.
- 2009 Elected Fellow of the Microscopy Society of America.
- 2012 Twenty Third Annual Distinguished Lecturer in Physiology and Biophysics, Virginia Commonwealth University, School of Medicine.
- 2013 Invitation to participate in the 23rd Solvay Conference in Chemistry
- 2013 Invited Public Lecture at the 23rd Solvay Conference in Chemistry
- 2014 Franklin Medal for Life Science
- 2014 Schwartz Lecture in Structural & Chemical Biology at Mount Sinai

Membership in Societies:

Biophysical Society,
 Protein Society,
 RNA Society,
 Microscopy Society of America,
 American Society for the Advancement of Science,
 National Academy of Sciences,
 American Academy for Arts and Sciences,
 American Academy of Microbiology.

Research Appointments Held

- 1964-1967 Research for Diplom thesis (Physics), Department of Physics, Universität München
- 1967-1970 Research Assistant, Max-Planck Institut für Eiweiss-und Lederforschung (later MPI for Biochemistry).
- 1970-1972 Two years of postdoctoral research experience in the USA, awarded by the Harkness Fellowships: (a) Research under Dr. R. Nathan, Image Processing Group, Science data analysis section Jet Propulsion Laboratory, California Institute of Technology Pasadena, (b) Research under Prof. R. M. Glaeser, Donner Laboratory, Department of Medical Physics, University of California, Berkeley; (c) Research under Prof. B.M. Siegel, Dept. of Applied Physics, Cornell University, Ithaca.
- 1972-1973 Visiting Scientist, Abteilung Strukturforschung I, Max-Planck Institute for Biochemistry, Martinsried b. München, W. Germany. Work in theoretical electron optics.
- 1973-1975 Senior Research Assistant, Electron Microscopy Group, Cavendish Laboratory, Department of Physics, Univ. of Cambridge, England. Research in electron optics, and taught Lecture series on image processing.
- 1975-1998 Senior Research Scientist, Wadsworth Center, New York State Department of Health.
- April-Sept. 1987 Sabbatical leave under the Fogarty Senior International Fellowship Program. Medical Research Council, Cambridge, England. Sponsor: Dr. Richard Henderson.
- July-Dec. 1994 Sabbatical leave at Max Planck Institute for Medical Research, Heidelberg, Germany. Funded by Humboldt Fellowship. Sponsor: Dr. Ken Holmes.

1994-present	Lab Chief, Laboratory for Computational Biology and Molecular Imaging.
1997-present	Research Professor, New York University, Department of Cell Biology.
1998-present	Howard Hughes Medical Institute Investigator.
2003-2008	Senior Lecturer, Department of Biochemistry and Molecular Biophysics, Columbia University.
2008-present	Professor, Department of Biochemistry and Molecular Biophysics, College of Physicians and Surgeons, Columbia University
2008-present	Professor, Department of Biological Sciences, College of Arts and Sciences, Columbia University

C. Teaching Experience

1a) Academic formal instruction.

1974-1975	Cavendish Laboratory, Cambridge. Taught a lecture series on image processing. Enrollment ~ 30 graduate students.
1977-1979	SUNY Computer Science Department - Visiting Associate Professor. Graduate course on image processing. Enrollment ~ 10 students.
1982-1985	SUNY Biology Department - Visiting Associate Professor. Various lectures on image processing and electron tomography given as part of advanced graduate courses.
1987-2008	Participation in SUNY graduate courses in Biophysics, Electron Microscopy I and II.
2001-2004	Organized SUNY BMS635 "Methods of Structural Biology". Number of students fluctuating between 4 and 10. Starting 2005, quorum was not reached.
2002	Contributed a class to BMS601a (Introduction to Biomedical Sciences): "Structural basis of antibiotics resistance."
2003	Organized Module II of a 3-module graduate course BMS601a (Introduction to Biomedical Sciences). Theme of the module: Structural aspects of gene expression.
2004	Contributed two lectures on translation in eukaryotes to graduate course in School of Arts and Sciences, Columbia University.
2005-present	Instructor in annual fall Course in Cryo-EM at the New York Structural Biology Center, organized by Prof. David Stokes, NYU. Enrollment ~10-25 graduate students from all NYSBC-sponsoring universities, including Columbia University. Prepared two weeks of the Course (introduction into mathematical methods in single particle reconstruction), interacted with Course director regarding the organization of the course. In 2005 and 2006 the course was simulcast at the Wadsworth Center and offered as a credit course to Biomedical Science students. In 2006 the book "Three-dimensional Electron Microscopy of Macromolecular Assemblies" by J. Frank, Oxford University Press 2006, was adopted as a course textbook.

1b) Workshops taught and organized

1978	Biozentrum Basel. Lecturer at EMBO course on image processing. Enrollment ~20 international participants.
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- 1980 Technische Akademie in Esslingen, Germany. Tutorial lecture on new methods in electron image processing.
- 1982 EMBL Heidelberg. Lecturer and instructor at EMBO course on image processing.
- 1987 Organized a two-day workshop on Image Processing in High Voltage Electron Microscopy.
- 1989 Organized (together with Michael Radermacher) an intensive 1-week image processing course at the Wadsworth Center. Enrollment ~15.
- 1990 Organized (together with Ross Smith and David Hillman, NYU) a 3-day course on image processing at the Pittsburgh Supercomputer Center.
- 1999 Organized (together with Pawel Penczek and Christian Spahn) a 3-day course on image processing at the Pittsburgh Supercomputer Center.
- 2003, 2005, 2007, 2009, 2011: Participated in the teaching of the cryo-EM Workshop at The Scripps Institute
- 2007 Organized Workshop on SPIDER Image Processing of Electron Micrographs. 50 international participants.

2) Sponsorships, mentorships, etc.

Graduate Thesis Advisor: Adriana Verschoor (SUNY Biology, 1989), Neng Yu Zhang (SUNY Physics, 1992), Weiping Liu (SUNY Physics, 1992), Yu Liu (SUNY Physics, 1994), Jun Zhu (SUNY Biomedical Sciences, 1995), Li Qi (SUNY Biomedical Sciences 2002), Ning Gao (SUNY Biomedical Sciences, 2006), Jie Fu (SUNY Biomedical Sciences), Ingrid Hahn (SUNY Biomedical Sciences), Bo Chen (Columbia University Biology, 2015), Drew Kennedy (Columbia University Biology, discontinued), Danny Nam Ho (Columbia University Biology, 2014), Amy Jobe (Columbia University Biology, current), Ming Sun (Columbia University Biology, 2016), Cristina Gutierrez-Vargas (Columbia University Biology, current), Jack Fu (Columbia University CMBS, current), Edward Twomey (Columbia University CBMS, current).

Graduate Thesis Committees: Marin van Heel (University of Groningen, The Netherlands, 1981), Cameron Street (University of Pennsylvania, 1987), Nicolas Boisset (University of Paris, 1990), Xiau-Wei Guo (SUNY Physics), Fei Li (SUNY Biomedical Sciences, 2004), Joshua Strauss (SUNY Biomedical Sciences, 2007), Miroslav Kalinowski (City University of New York, Computer Sciences, 2007), Martin Kampmann (Rockefeller University 2009), Jingyi Fei (Columbia University, Chemistry 2010), Anke Mulder (The Scripps Research Institute, 2010), Jiangning Wang (Columbia University, Chemistry 2010), Daniel MacDougall (Columbia University, Chemistry 2011).

Undergraduate mentoring: Supervised numerous undergraduates in 2- and 4-credit research projects on selected topics of electron microscopy and computer image processing, as well as summer REU projects.

Postdoctoral students (*since 1981 – current postdocs are highlighted in bold*):

Francisco Acosta-Reyes, Xabier Agirrazabala, Rajendra K. Agrawal, Greg Allen, Nicolas Boisset, Jose-Maria Carazo, Magali Cottevieille, Sanchaita Das, Amedee DesGeorges, **Marcus Fislage**, Jie Fu, Irene Gabashvili, Haixiao Gao, Ning Gao, Cheri Hampton, Yaser Hashem, Maria Gomez-Lorenzo, Sukhjit Kaur, Ramani Kharidehal, Robert Langlois, Jianlin Lei, **Wen Li**, **Hstau Liao**, Weiping (Mark) Liu, **Sandip Kaledhonkar**, **Zheng Liu**, **Suvrajit Maji**, Arun Malhotra, **Andrey Maljutin**, Bruce McEwen, Kakoli Mitra, Jesper Pallesen, Pawel Penczek, Paxton Provitera, Michael Radermacher, Bimal Rath, Urmila Rawat, Montserrat Samso, Jayati Sengupta, Gyanesh Sharma, **Bingxin Shen**, Christian M.T. Spahn, Suman Srivastava, Derek Taylor, Mikel Valle, Adriana

Verschoor, Terence Wagenknecht, Jun Zhu.

D. Employment Record

- 1964-1967 Research Assistant while working on Diplom thesis (Physics), Department of Physics, Universität München.
- 1967-1970 Research Assistant, Max-Planck Institut für Eiweiss-und Lederforschung (later MPI for Biochemistry).
- 1970-1972 Two years of postdoctoral research experience in the USA, awarded by the Harkness Fellowships: (a) Research under Dr. R. Nathan, Image Processing Group, Science data analysis section Jet Propulsion Laboratory, California Institute of Technology Pasadena, (b) Research under Prof. R. M. Glaeser, Donner Laboratory, Department of Medical Physics, University of California, Berkeley; (c) Research under Prof. B.M. Siegel, Dept. of Applied Physics, Cornell University, Ithaca.
- 1972-1973 Visiting Scientist, Abteilung Strukturforschung I, Max-Planck Institute for Biochemistry, Martinsried b. München, W. Germany. Work in theoretical electron optics.
- 1973-1975 Senior Research Assistant, Electron Microscopy Group, Cavendish Laboratory, Department of Physics, Univ. of Cambridge, England. Research in electron optics, and taught Lecture series on image processing.
- 1975-1998 Senior Research Scientist, Wadsworth Center, New York State Department of Health.
- 1976-1980 Visiting Associate Professor, Computer Science Department, SUNY at Albany. Taught Graduate course on image processing.
- 1982-present Visiting Associate Professor, Biology Department, SUNY at Albany. Supervision of graduate and undergraduate research projects.
- 1986-2007 Professor, Department of Biomedical Sciences, School of Public Health, SUNY at Albany. [will change to Adjunct status]
- April-Sept. 1987 Sabbatical leave under the Fogarty Senior International Fellowship Program. Medical Research Council, Cambridge, England. Sponsor: Dr. Richard Henderson.
- July-Dec. 1994 Sabbatical leave at Max Planck Institute for Medical Research, Heidelberg, Germany. Funded by Humboldt Fellowship. Sponsor: Dr. Ken Holmes.
- 1994-2007 Lab Chief, Laboratory for Computational Biology and Molecular Imaging.
- 1997-present Research Professor, New York University, Department of Cell Biology.
- 1998-present Howard Hughes Medical Institute Investigator.
- 2003-2008 Senior Lecturer, Department of Biochemistry and Molecular Biophysics, Columbia University, College of Physicians and Surgeons.
- 2008-present Professor, Department of Biochemistry and Molecular Biophysics, Columbia University, College of Physicians and Surgeons.
- 2008-present Professor, Department of Biological Sciences, Columbia University.

E. Publications

REFEREED ORIGINAL MANUSCRIPTS

1. W. Hoppe, R. Langer, J. Frank and A. Feltynowski. Bilddifferenzverfahren in der Elektronenmikroskopie. *Naturwissenschaften* 56, 267-272 (1969).
2. J. Frank. Nachweis von Objektbewegungen im lichtoptischen Diffraktogramm von elektronenmikroskopischen Aufnahmen. *Optik* 30, 171-180 (1969).
3. J. Frank. A study on heavy/light atom discrimination in bright field electron microscopy.

- Biophys. J. 12, 484-511 (1972).
4. J. Frank. Observation of the relative phases of electron microscopic phase contrast zones with the aid of the optical diffractometer. *Optik* 35, 608-612 (1972).
 5. J. Frank. The envelope of electron microscopic transfer functions for partially coherent illumination. *Optik* 38, 519-539 (1973).
 6. J. Frank. Radiation damage assessment from electron images using digital correlation methods. *J. Phys. D: Appl. Phys.* 7, L75-L78 (1974).
 7. J. Frank. Phasenbestimmung und Berücksichtigung der Linsenfehler in der Elektronenmikroskopie; eine Klarstellung. *Optik* 41, 90-91 (1974/75).
 8. J. Frank. A practical resolution criterion in optics and electron microscopy. *Optik* 43, 25-34 (1975).
 9. J. Frank. Controlled focusing and stigmatism in the conventional and scanning transmission electron microscope. *J. Phys. E: Sci. Instr.* 8, 582-587 (1975).
 10. J. Frank and L. Al-Ali. Signal-to-noise ratio of electron micrographs obtained by cross-correlation. *Nature* 256, 376-378 (1975).
 11. J. Frank. Averaging of low-exposure electron micrographs of non-periodic objects. *Ultramicroscopy* 1, 159-162 (1975).
 12. M. Beer, J. Frank, K.-J. Hanszen, E. Kellenberger and R.C. Williams. The possibilities and prospects of obtaining high-resolution information (below 30 Å) on biological material using the electron microscope. *Quart. Rev. Biophys.* 1: 211-238.
 13. J. Frank. Determination of source size and energy spread from electron micrographs using the method of Young's fringes. *Optik* 44, 379-391 (1976).
 14. J. Frank. Partial coherence and efficient use of electrons in bright field electron microscopy. *Optik* 43, 103-109 (1975).
 15. R.H. Wade and J. Frank. Electron microscopic transfer functions for partially coherent axial illumination and chromatic defocus spread. *Optik* 49, 81-92 (1977).
 16. W.O. Saxton and J. Frank. Motif detection in quantum noise-limited electron micrographs by cross-correlation. *Ultramicroscopy* 2, 219-227 (1977).
 17. J. Frank, S.C. McFarlane and K.H. Downing. A note on the effect of source size and defocus spread in bright-field electron microscopy. *Optik* 52, 49-60 (1978).
 18. J. Frank, W. Goldfarb, D. Eisenberg, and T.S. Baker. Reconstruction of glutamine synthetase using computer averaging. *Ultramicroscopy* 3, 283-290 (1978).
 19. M. Kessel, J. Frank and W. Goldfarb. Averages of glutamine synthetase molecules as obtained with various stain and electron dose conditions. *J. Supramol. Str.* 14, 405-422 (1980).
 20. J. Frank, W. Goldfarb, D. Eisenberg and T.S. Baker. Addendum to reconstruction of glutamine synthetase using computer averaging. *Ultramicroscopy* 4, 274 (1978).
 21. J. Frank and M. van Heel. Intelligent averaging of single molecule using computer alignment and correspondence analysis: I. The basic method. *Elect. Microsc.* 2, 690-693 (1980).
 22. H.P. Zingsheim, D.-Ch. Neugebauer, F.J. Barrantes and J. Frank. Structural details of membrane-bound acetylcholine receptor from *Torpedo marmorata*. *PNAS* 77, 952-956 (1980).
 23. L. Al-Ali and J. Frank. Resolution estimation in electron microscopy. *Optik* 56, 31 (1980).
 24. M. van Heel and J. Frank. Use of multivariate statistics in analysing the images of biological macromolecules. *Ultramicroscopy* 6, 187-194 (1981).
 25. J. Frank, B. Shimkin and H. Dowse. SPIDER - A modular software system for image processing. *Ultramicroscopy* 6, 343 (1981).
 26. J. Frank, A. Verschoor and M. Boublik. Computer averaging of electron micrographs of 40S ribosomal subunits. *Science* 214, 1353-1355 (1981).
 27. C. Mannella and J. Frank. Effects of divalent metal ions and chelators on the structure of the outer mitochondrial membranes from *Neurospora crassa*. *Biophys. J.* 37, 3 (1982).
 28. J. Frank. Methods for studying the dynamic behavior of biological macromolecules. *Ultramicroscopy* 9, 3-8 (1982).

29. H.P. Zingsheim, D.-Ch. Neugebauer, J. Frank, W. Haenicke and F.J. Barrantes. Dimeric arrangement and structure of the membrane-bound acetylcholine receptor protein studied by electron microscopy. *EMBO J.* 1, 541-547 (1982).
30. H.P. Zingsheim, F.J. Barrantes, J. Frank, W. Haenicke and D.-Ch. Neugebauer. Direct structural localization of two toxin recognition sites on an acetylcholine receptor protein. *Nature* 299, 81-84 (1982).
31. P.-Y. Sizaret, J. Frank, J. Lamy, J. Weill and J.N. Lamy. A refined quaternary structure of *Androctonus australis* hemocyanin. *Eur. J. Biochem.* 127, 501-506 (1982).
32. J. Frank, A. Verschoor and M. Boublik. Multivariate statistical analysis of ribosome electron micrographs -- L and R lateral views of the 40S subunit from HeLa cells. *J. Mol. Biol.* 161, 107-137 (1982).
33. J. Lamy, P.-Y. Sizaret, J. Frank, A. Verschoor, R. Feldmann and J. Bonaventura. Architecture of *Limulus polyphemus* hemocyanin. *Biochemistry* 21, 6825-6833 (1982).
34. J. Frank. New methods for averaging non-periodic objects and distorted crystals in biologic electron microscopy. *Optik* 63, 67-69 (1982).
35. W. Haenicke, J. Frank and H.-P. Zingsheim. Statistical significance of molecule projections by single particle averaging. *J. Microscopy* 133, 223-238 (1984).
36. C.A. Mannella, M. Colombini and J. Frank. Structural and functional evidence for multiple channel complexes in the outer membrane of *Neurospora crassa* mitochondria. *PNAS* 80, 2234-2247 (1983).
37. C.A. Mannella and J. Frank. Electron microscopic stains as probes of the surface charge of mitochondrial outer membrane channels. *Biophys. J.* 45, 139-141 (1984).
38. T. Wagenknecht and J. Frank. Localization of lipoyl-bearing domains in 2-ketoglutarate dehydrogenase complex by electron microscopy and single-particle averaging methods. *Biochemistry* 23, 3383-3389 (1984).
39. J. Frank and T. Wagenknecht. Automatic selection of molecular images from electron micrographs. *Ultramicroscopy* 12, 169 (1984).
40. M. Radermacher and J. Frank. Representation of objects reconstructed in 3-D by surfaces of equal density. *J. Microscopy* 136, 77-85 (1984).
41. A. Verschoor, J. Frank, M. Radermacher, T. Wagenknecht and M. Boublik. Three-dimensional reconstruction of the 30S ribosomal subunit from randomly oriented particles. *J. Mol. Biol.* 178, 677-698 (1984).
42. C.L.F. Woodcock and J. Frank. Nucleosome mass distribution using image averaging. *J. Ultrastruct. Res.* 89, 295-302 (1984).
43. M. Kessel, M. Radermacher and J. Frank. The structure of the stalk surface layer of a brine pond microorganism: Correlation averaging applied to a double layered lattice structure. *J. Microscopy* 139, 63-74 (1985).
44. J.A. Subirana, S. Munoz-Guerra, J. Aymami, M. Radermacher and J. Frank. The layered organization of nucleosomes in 30 nm chromatin fibers. *Chromosoma* 91, 377-390 (1985).
45. J. Lamy, J. Lamy, P. Billiard, P.-Y. Sizaret, G. Cavé, J. Frank and G. Motta. An approach to the direct intramolecular localization of antigenic determinants in *Androctonus australis* hemocyanin with monoclonal antibodies by molecular immunoelectron microscopy. *Biochemistry* 24, 5532-5542 (1985).
46. D.F. Parsons, M. Marko, M. Radermacher and J. Frank. Shape changes and polarization of cells migrating through tissue. A high-voltage electron microscope and computer graphics study of serial thick sections. *Tissue and Cell* 17, 491-510 (1985).
47. M. Radermacher and J. Frank. Use of non-linear mapping in multivariate analysis of molecule projections. *Ultramicroscopy* 17, 117-126 (1985).
48. S.W. Hui and J. Frank. Analysis of the irregular planar distribution of proteins in membranes. *J. Microscopy* 137, 293-303 (1985).
49. M. Tsuji, J. Frank and R. St. J. Manley. Image analysis in the electron microscopy of cellulose

- protofibrils II. Digital Correlation Methods. *Colloid and Polymer Science* 264, 89-96 (1986).
50. A. Verschoor, J. Frank and M. Boublik. Investigation of the 50S ribosomal subunit by electron microscopy and image analysis. *J. Ultrastr. Res.* 92, 180-189 (1985).
 51. A. Verschoor, J. Frank, T. Wagenknecht and M. Boublik. Computer averaged views of the 70S monosome from *E. coli*. *J. Mol. Biol.* 187, 581-590 (1986).
 52. C.A. Mannella, A. Ribeiro and J. Frank. Structure of the channels in the outer mitochondrial membrane: Electron microscopic studies of the periodic arrays induced by phospholipase A2 treatment of the *Neurospora* membrane. *Biophys. J.* 49, 307-318 (1986).
 53. M. Radermacher, T. Wagenknecht, A. Verschoor and J. Frank. A new 3-D reconstruction scheme applied to the 50S ribosomal subunit of *E. coli*. *J. Microscopy* 141, RP1 (1986).
 54. B.F. McEwen, M. Radermacher, C.L. Rieder and J. Frank. Tomographic three-dimensional reconstruction of cilia ultrastructure from thick sections. *Proc. Natl. Acad. Sci. (USA)* 83, 9040-9044 (1986).
 55. J.P. Breaudiere and J. Frank. Reconstitution of molecule images analyzed by correspondence analysis: a tool for structural interpretation. *J. Microscopy* 144, 1-14 (1986).
 56. M. Radermacher, T. Wagenknecht, A. Verschoor and J. Frank. Three-dimensional reconstruction from a single-exposure random conical tilt series applied to the 50S ribosomal subunit of *Escherichia coli*. *J. Microscopy* 146, 113-136 (1987).
 57. J. Frank, B.F. McEwen, M. Radermacher, J.N. Turner and C.L. Rieder. Three-dimensional tomographic reconstruction in high voltage electron microscopy. *J. Electron Microscopy Tech.* 6, 193-205 (1987).
 58. M. Radermacher, T. Wagenknecht, A. Verschoor and J. Frank. Three-dimensional structure of the large ribosomal subunit from *Escherichia coli*. *EMBO J.* 6, 1107-1114 (1987).
 59. N. Boisset, J. Frank, J.C. Taveau, P. Billiald, G. Motta, J. Lamy, P.Y. Sizaret and J. Lamy. Intramolecular localization of epitopes within an oligomeric protein by immuno-electron microscopy and image processing. *Proteins* 3, 161-183 (1988).
 60. J.M. Carazo and J. Frank. Three-dimensional matching of macromolecular structures obtained from electron microscopy: an application to the 70S and 50S *E. coli* ribosomal particles. *Ultramicroscopy* 25, 13-22 (1988).
 61. T. Wagenknecht, R. Grassucci and J. Frank. Electron microscopy and computer image averaging of ice-embedded large ribosomal subunits from *E. coli*. *J. Mol. Biol.* 199, 137-147 (1988).
 62. J.M. Carazo, T. Wagenknecht, M. Radermacher, V. Mandiyan, M. Boublik and J. Frank. Three-dimensional structure of 50S *E. coli* ribosomal subunits depleted of proteins L7/L12. *J. Mol. Biol.* 201, 393-404 (1988).
 63. J. Frank, J.P. Breaudiere, J.M. Carazo, A. Verschoor and T. Wagenknecht. Classification of images of biomolecular assemblies: a study of ribosomes and ribosomal subunits of *E. coli*. *J. Microscopy* 105, 99-115 (1988).
 64. A. Saito, M. Inui, M. Radermacher, J. Frank and S. Fleischer. Ultrastructure of the calcium release channel of sarcoplasmic reticulum. *J. Cell Biol.* 107, 211-219 (1988).
 65. T. Wagenknecht, J. Frank, M. Boublik, K. Nurse and J. Ofengand. Direct localization of the tRNA-anticodon interaction site on the *E. coli* 30S ribosomal subunit by electron microscopy and computerized image averaging. *J. Mol. Biol.* 203, 753-760 (1988).
 66. J. Frank, W. Chiu and L. Degn. The characterization of structural variations within a crystal field. *Ultramicroscopy* 26, 345-360 (1988).
 67. T. Wagenknecht, R. Grassucci, J. Frank, A. Saito, M. Inui and S. Fleischer. Three-dimensional architecture of the calcium channel/foot structure of sarcoplasmic reticulum. *Nature* 338, 167-170 (1989).
 68. T. Wagenknecht, J-M. Carazo, M. Radermacher and J. Frank. Three-dimensional reconstruction of the ribosome from *Escherichia coli*. *Biophys. J.* 55, 455-464 (1989).
 69. J-M. Carazo, T. Wagenknecht and J. Frank. Variations of the three-dimensional structure of the *Escherichia coli* ribosome in the range of overlap views. *Biophys. J.* 55, 465-477 (1989).

70. M. Unser, B.L. Trus, J. Frank and A.C. Steven. The spectral signal-to-noise ratio resolution criterion: Computational efficiency and statistical precision. *Ultramicroscopy* 30, 429-434 (1989).
71. A. Verschoor, N.Y. Zhang, T. Wagenknecht, T. Obrig, M. Radermacher and J. Frank. Three-dimensional reconstructions of mammalian 40S ribosomal subunit. *J. Mol. Biol.* 209, 115-126 (1989).
72. J-M. Carazo, F.F. Rivera, E.L. Zapata, M. Radermacher and J. Frank. Fuzzy-sets based classification of electron microscopy images of biological macromolecules with an application to ribosomal particles. *J. Microscopy* 157, 187-203 (1990).
73. N. Boisset, J.-C. Taveau, J. Lamy, T. Wagenknecht, M. Radermacher and J. Frank. Three-dimensional reconstruction of native *Androctonus australis* hemocyanin. *J. Mol. Biol.* 216, 743-760 (1990).
74. A. Verschoor and J. Frank. Three-dimensional structure of the mammalian cytoplasmic ribosome. *J. Mol. Biol.* 214, 737-749 (1990).
75. C.L. Woodcock, B.F. McEwen and J. Frank. Ultrastructure of chromatin. II. Three-dimensional reconstruction of isolated fibers. *J. Cell Sci.* 99, 107-114 (1991).
76. J. Frank, P. Penczek, R. Grassucci and S. Srivastava. Three-dimensional reconstruction of the 70S *Escherichia coli* ribosome in ice: the distribution of ribosomal RNA. *J. Cell Biol.* 115, 597-605 (1991).
77. P. Penczek, M. Radermacher and J. Frank. Three-dimensional reconstruction of single particles embedded in ice. *Ultramicroscopy* 40, 33-53 (1992).
78. M. Radermacher, T. Wagenknecht, R. Grassucci, J. Frank, M. Inui, C. Chadwick and S. Fleischer. Cryo-EM of the native structure of the calcium release channel/ryanodine receptor from sarcoplasmic reticulum. *Biophys. J.* 61, 936-940 (1992).
79. D.G. Morgan, R.A. Grant, W. Chiu and J. Frank. Patch averaging of electron images of GP32*I crystals with variable thickness. *J. Struct. Biol.* 108, 245-256 (1992).
80. C.J. Wilson, D.N. Mastronade, B.F. McEwen and J. Frank. Measurement of neuronal surface area using high voltage electron microscope tomography. *NeuroImage*, 1, 11-22 (1992).
81. D. Barnard, J.N. Turner, J. Frank and B.F. McEwen. A 360E single-axis tilt stage for the high-voltage electron microscope. *J. Microscopy* 167, 39-48 (1992).
82. S. Srivastava, A. Verschoor and J. Frank. Eukaryotic initiation factor 3 does not prevent association through physical blockage of the ribosomal subunit-subunit p interface. *J. Mol. Biol.*, 226, 301-304 (1992).
83. N. Boisset, R. Grassucci, P. Penczek, E. Delain, F. Pochon, J. Frank and J.N. Lamy. Three-dimensional reconstruction of a complex of human α 2-macroglobulin with monomaleimido nanogold (Au₉) embedded in ice. *J. Struct. Biol.* 109, 39-45 (1993).
84. B.F. McEwen, J. Arena, J. Frank and C.L. Rieder. Structure of the colcemid-treated Ptk kinetochore outer plate as determined by high voltage electron microscopic tomography. *J. Cell Biol.* 120, 301-312 (1993).
85. N. Boisset, P. Penczek, F. Pochon, J. Frank and J. Lamy. Three-dimensional architecture of the human α 2-macroglobulin transformed with methylamine. *J. Mol. Biol.* 232, 522-529 (1993).
86. N. Boisset, M. Radermacher, R. Grassucci, J.C. Taveau, W. Liu, J. Lamy, J. Frank and J.N. Lamy. Three-dimensional immunoelectron microscopy of scorpion Fab Fragment. *J. Struct. Biol.* 111, 234-244 (1993).
87. P. Penczek, R. Grassucci and J. Frank. The ribosome at improved resolution: new techniques for merging and orientation refinement in 3D cryo electron microscopy of biological particles. *Ultramicroscopy* 53, 251-270 (1994).
88. C. Mannella, M. Marko, P. Penczek, D. Barnard and J. Frank. The internal compartmentation of rat-liver mitochondria: tomographic study using the high-voltage transmission electron microscope. *Microsc. Res. Tech.* 27, 278-283 (1994).
89. O. Lambert, N. Boisset, P. Penczek, J. Lamy, J.-C. Taveau, J. Frank and J.N. Lamy. Quarternary structure of *Octopus vulgaris* hemocyanin: three-dimensional reconstruction from frozen-hydrated

- specimens and intramolecular location of functional units *O_ve* and *O_vb*. *J. Mol. Biol.* 238, 75-87 (1994).
90. N. Boisset, P. Penczek, F. Pochon, J. Frank and J. Lamy. Three-dimensional reconstruction of human α_2 -macroglobulin and refinement of the localization of thiol ester bonds with monomaleimido nanagold. *Ann. NY Acad. Sci.* 737, 229-244 (1994).
 91. M. Radermacher, V. Rao, R. Grassucci, J. Frank, A. Timerman, S. Fleischer and T. Wagenknecht. Cryo-electron microscopy and three-dimensional reconstruction of the calcium release channel/ryanodine receptor from skeletal muscle. *J. Cell. Biol.* 2, 411-423 (1994).
 92. J. Frank and P. Penczek. On the correction of the contrast transfer function in biological electron microscopy. *Optik* 98, 125-129 (1995).
 93. P. Penczek, M. Marko, K. Buttle and J. Frank. Double-tilt electron tomography. *Ultramicroscopy* 60, 393-410.
 94. Y. Liu, P. Penczek, B. McEwen and J. Frank. A marker-free alignment method for electron tomography. *Ultramicroscopy* 58, 393-402 (1995).
 95. S. Srivastava, A. Verschoor, M. Radermacher, R. Grassucci and J. Frank. Three-dimensional reconstruction of mammalian 40S ribosomal subunit embedded in ice. *J. Mol. Biol.* 245, 461-466 (1995).
 96. R. Lata, P. Penczek and J. Frank. Automatic particle picking from electron micrographs. *Ultramicroscopy* 58, 381-391 (1995).
 97. J. Frank, J. Zhu, P. Penczek, Y. Li, S. Srivastava, A. Verschoor, M. Radermacher, R. Grassucci, R. K. Lata and R.K. Agrawal. A model of protein synthesis based on a new cryo-electron microscopy reconstruction of the *E. coli* ribosome. *Nature* 376, 441-444 (1995).
 98. W. Liu and J. Frank. Estimation of variance distribution in three-dimensional reconstruction: I. Theory. *J. Opt. Soc. Am. A* 12, 2615-2627 (1995).
 99. W. Liu, N. Boisset and J. Frank. Estimation of variance distribution in three-dimensional reconstruction: II. Applications. *J. Opt. Soc. Am. A* 12, 2628-2635 (1995).
 100. N. Boisset, P. Penczek, J.C. Taveau, J. Lamy, J. Frank and J. Lamy. Three-dimensional reconstruction of *Androctonus australis* hemocyanin labeled with a monoclonal fab fragment. *J. Struct. Biol.* 115, 16-29 (1995).
 101. R.K. Agrawal, P. Penczek, R.A. Grassucci, Y. Li, A. Leith, K.H. Nierhaus and J. Frank. Direct visualization of A-, P-, and E-site transfer RNAs in the *Escherichia coli* ribosome. *Science* 271, 1000-1002 (1996).
 102. R. Marabini, C. Vaquerizo and J.J. Fernandez, J.M. Carazo, A. Engel and J. Frank. Proposal for a new distributed database of macromolecular and subcellular structures from different areas of microscopy. *J. Struct. Biol.* 116, 161-166 (1996).
 103. A. Verschoor, S. Srivastava, R. Grassucci and J. Frank. Native 3D structure of eukaryotic 80S ribosome: morphological homology with the *E. coli* 70S ribosome. *J. Cell Biol.* 133, 495-505 (1996).
 104. J. Frank, M. Radermacher, P. Penczek, J. Zhu, Y. Li, M. Ladjadj and A. Leith. SPIDER and WEB: processing and visualization of images in 3D electron microscopy and related fields. *J. Struct. Biol.* 116, 190-199 (1996).
 105. K.R. Lata, R.K. Agrawal, P. Penczek, R. Grassucci, J. Zhu and J. Frank. Three-dimensional reconstruction of *Escherichia coli* 30S ribosomal subunit in ice. *J. Mol. Biol.* 262, 43-52 (1996).
 106. P. Penczek, J. Zhu and J. Frank. A common-lines based method for determining orientations for $N > 3$ particle projections simultaneously. *Ultramicroscopy* 63, 205-218 (1996).
 107. J. Frank. The ribosome at higher resolution – the donut takes shape. *Curr. Opin. Struct. Biol.* 7, 266-272 (1997).
 108. Y. Li, A. Leith and J. Frank. Tinkerbelle – a tool for interactive segmentation of 3D data. *J. Struct. Biol.* 120, 266-275 (1997).
 109. B.K. Rath, M. Marko, M. Radermacher and J. Frank. Low-dose automated electron tomography: a recent implementation. *J. Struct. Biol.* 120, 210-218 (1997).

110. J. Zhu, P.A. Penczek, R. Schröder and J. Frank. Three-dimensional reconstruction with CTF correction from energy-filtered cryo-electron micrographs: Procedure and application to the 70S *Escherichia coli* ribosome. *J. Struct. Biol.* 118, 197-219 (1997).
111. R. Beckmann, D. Bubeck, R. Grassucci, P. Penczek, A. Verschoor, G. Blobel and J. Frank. Alignment of conduits for the nascent polypeptide chain in the ribosome-Sec61 complex. *Science* 278, 2123-2126 (1997).
112. A. Malhotra, P. Penczek, R.K. Agrawal, I.S. Gabashvili, R.A. Grassucci, R. Jünemann, N. Burkhardt, K.H. Nierhaus and J. Frank. *Escherichia coli* 70S ribosome at 15-Å resolution by cryo-electron microscopy: localization of fMet-tRNA^{Met} and fitting of L1 protein. *J. Mol. Biol.* 280, 103-115 (1998).
113. J. Frank and R.K. Agrawal. The movement of tRNA through the ribosome. *Biophys. J.* 74, 589-594 (1998).
114. R.K. Agrawal, P. Penczek, R.A. Grassucci and J. Frank. Visualization of elongation factor G on the *Escherichia coli* ribosome: The mechanism of translocation. *Proc. Natl. Acad. Sci. (USA)* 95, 6134-6138 (1998).
115. N. Ban, B. Freeborn, P. Nisson, P. Penczek, R.A. Grassucci, R. Sweet, J. Frank, P.B. Moore and T.A. Steitz. A 9Å resolution X-ray crystallographic map of the large ribosomal subunit. *Cell* 93, 1105-1115 (1998).
116. A. Verschoor, J.A. Warner, S. Srivastava, R.A. Grassucci and J. Frank. Three-dimensional structure of the yeast ribosome. *Nucleic Acids Res.* 26, 655-661 (1998).
117. R.K. Agrawal, P. Penczek, R.A. Grassucci, N. Burkhardt, K.H. Nierhaus and J. Frank. Effect of buffer conditions on the position of tRNA on the 70S ribosome as visualized by cryoelectron microscopy. *J. Biol. Chem.* 274, 8723-8729 (1999).
118. R.A. Agrawal and J. Frank. Structural studies of the translational apparatus. *Curr. Opin. Struct. Biol.* 9, 215-221 (1999).
119. I.S. Gabashvili, R.K. Agrawal, R. Grassucci and J. Frank. Structure and structural variations of the *Escherichia coli* 30S ribosomal subunit as revealed by three-dimensional cryo-electron microscopy. *J. Mol. Biol.* 286, 1285-1291 (1999).
120. R.K. Agrawal, A.B. Heagle, P. Penczek, R.A. Grassucci and J. Frank. EF-G dependent GTP hydrolysis induces translocation accompanied by large conformational changes in the 70S ribosome. *Nat. Struct. Biol.* 6, 643-647 (1999).
121. J.P. McCutcheon, R.K. Agrawal, S.M. Philips, R.A. Grassucci, S.E. Gerchman, W.M. Clemons, Jr., V. Ramakrishnan and J. Frank. Location of translational initiation factor IF3 on the small ribosomal subunit. *PNAS* 96, 4301-4306 (1999).
122. I.S. Gabashvili, R.K. Agrawal, R. Grassucci, C.L. Squires, A.E. Dahlberg and J. Frank. Major rearrangements in the 70S ribosomal 3D structure caused by a conformational switch in 16S ribosomal RNA. *EMBO J.* 18, 6501-6507 (1999).
123. C.M.T. Spahn, R.A. Grassucci, P. Penczek and J. Frank. Direct three-dimensional localization and positive identification of RNA helices within the ribosome by means of genetic tagging and cryo-electron microscopy. *Structure* 7, 1567-1573 (1999).
124. J. Frank, A.B. Heagle and R.K. Agrawal. Animation of the dynamical events of the elongation cycle based on cryoelectron microscopy of functional complexes of the ribosome. *J. Struct. Biol.* 128, 15-18 (1999).
125. I.S. Gabashvili, R.K. Agrawal, C.M.T. Spahn, R.A. Grassucci, D.I. Svergun, J. Frank and P. Penczek. Solution structure of the *E. coli* ribosome at 11.5 Å resolution. *Cell* 100, 51-63 (2000).
126. J. Frank and R.K. Agrawal. A ratchet-like inter-subunit reorganization of the ribosome during translocation. *Nature* 406, 318-322 (2000).
127. M.G. Gomez-Lorenzo, C.M.T. Spahn, R.K. Agrawal, R.A. Grassucci, P. Penczek, K. Chakraborty, J.P.G. Ballesta, J.L. Lavandera, J.F. Garcia-Bustos and J. Frank. Three-

- dimensional cryo-electron microscopy localization of EF2 in the *Saccharomyces cerevisiae* 80S ribosome at 17.5 Å resolution. *EMBO J.* 19, 2710-2718 (2000).
128. R.K. Agrawal, C.M.T. Spahn, P. Penczek, R.A. Grassucci, K.H. Nierhaus and J. Frank. Visualization of tRNA movements on the *Escherichia coli* 70S ribosome during the elongation cycle. *J. Cell Biol.* 150, 447-459 (2000).
 129. C.M.T. Spahn, P.A. Penczek, A. Leith and J. Frank. A method for differentiating proteins from nucleic acids in intermediate-resolution density maps: cryo-electron microscopy defines the quaternary structure of the *E. coli* 70S ribosome. *Structure* 8, 937-948 (2000).
 130. M.S. VanLoock, R.K. Agrawal, I.S. Gabashvili, L. Qi, J. Frank and S.C. Harvey. Movement of the decoding region of the 16S ribosomal RNA accompanies tRNA translocation. *J. Mol. Biol.* 304, 507-515 (2000).
 131. W. Wriggers, R.K. Agrawal, D.L. Drew, A. McCammon and J. Frank. Domain motions of EF-G bound to the 70S ribosome: insights from a hand-shaking between multi-resolution structures. *Biophys. J.* 79, 1670-1678 (2000).
 132. C.M.T. Spahn, J.S. Kieft, R.A. Grassucci, P. Penczek, K. Zhou, J.A. Doudna and J. Frank. Hepatitis C virus IRES RNA induced changes in the conformation of the 40S ribosomal subunit. *Science* 291, 1959-1962 (2001).
 133. C.M.T. Spahn, G. Blaha, R.K. Agrawal, P. Penczek, R.A. Grassucci, C.A. Trieber, S.R. Connell, D.E. Taylor, K.H. Nierhaus and J. Frank. Localization of the tetracycline resistance protein Tet(O) on the ribosome and the inhibition mechanism of tetracycline. *Mol. Cell* 7, 1037-1045 (2001).
 134. I.S. Gabashvili, S.T. Gregory, M. Valle, R. Grassucci, M. Worbs, M.C. Wahl, A.E. Dahlberg and J. Frank. The polypeptide tunnel system in the ribosome and its gating in erythromycin resistance mutants of L4 and L22. *Mol. Cell* 8, 181-188 (2001).
 135. R.K. Agrawal, J. Linde, J. Sengupta, K.H. Nierhaus and J. Frank. Localization of L11 protein on the ribosome and elucidation of its involvement in EF-G-dependent translocation. *J. Mol. Biol.* 311, 777-787 (2001).
 136. J. Sengupta, R.K. Agrawal and J. Frank. Visualization of protein S1 within the 30S ribosomal subunit. *PNAS*, 98, 11991-11996 (2001).
 137. B. McEwen and J. Frank. Electron tomographic and other approaches for imaging molecular machines. *Curr. Opin. Neurobiol.* 11, 594-600 (2001).
 138. C.M.T. Spahn, R. Beckmann, N. Eswar, P. Penczek, A. Sali, G. Blobel and J. Frank. Structure of the 80S ribosome from *Saccharomyces cerevisiae* – tRNA – ribosome and subunit-subunit interactions. *Cell* 107, 373-386 (2001).
 139. R. Beckmann, C.M.T. Spahn, N. Eswar, J. Helmers, P.A. Penczek, A. Sali, J. Frank and G. Blobel. Analysis of the protein-conducting channel associated with the translating 80S ribosome. *Cell* 107, 361-372 (2001).
 140. J. Frank and R.K. Agrawal. Ratchet-like movements between the two ribosomal subunits: their implications in elongation factor recognition and tRNA translocation. In *Cold Spring Harbor Symposia on Quantitative Biology: The Ribosome*, Vol. 66, pg 67-75 (2002).
 141. M. Valle, J. Sengupta, N.K. Swami, R.A. Grassucci, N. Burkhardt, K.H. Nierhaus, R.K. Agrawal and J. Frank. Cryo-EM reveals an active role for the aminoacyl-tRNA in the accommodation process. *EMBO J.* 21, 3557-3567 (2002).
 142. H. Gao, C.M.T. Spahn, R.A. Grassucci and J. Frank. An assay for local quality in cryo-electron micrographs of single particles. *Ultramicroscopy* 93, 169-178 (2002).
 143. S.M. Stagg, M. Valle, R.K. Agrawal, J. Frank, and S.C. Harvey. Problems with the transorientation hypothesis. *RNA*, 8, 1093-1094 (2002).
 144. U.B.S. Rawat, A.V. Zavialov, J. Sengupta, M. Valle, R.A. Grassucci, J. Linde, B. Vestergaard,

- M. Ehrenberg and J. Frank. A cryo-electron microscopic study of ribosome-bound termination factor RF2. *Nature* 421, 87-90 (2003).
145. M. Valle, A. Zavialov, J. Sengupta, U. Rawat, M. Ehrenberg, and J. Frank. Locking and unlocking of ribosomal motions. *Cell* 114, 123-134 (2003).
 146. T.R. Shaikh, R. Hegerl and J. Frank. An approach to examining model dependence in EM reconstructions using cross-validation. *J. Struct. Biol.* 142, 301-310 (2003).
 147. M. Valle, R. Gillet, S. Kaur, A. Henne, V. Ramakrishnan and J. Frank. Visualizing tmRNA entry into a stalled ribosome. *Science* 300, 127-130 (2003).
 148. M. Yarus, M. Valle and J. Frank. A twisted tRNA intermediate sets the threshold for decoding. *RNA* 9, 384-385 (2003).
 149. H. Gao., J. Sengupta, M. Valle, A. Korostelev, N. Eswar, S.M. Stagg, P. Van Roey, R.K. Agrawal, S.C. Harvey, A. Sali, M.S. Chapman and J. Frank. Study of the structural dynamics of the *E. coli* 70S ribosome using real space refinement. *Cell* 113, 789-801 (2003).
 150. M. Valle, A. Zavialov, W. Li, S.M. Stagg, J. Sengupta, R.C. Nielsen, P. Nissen, S.C. Harvey, M. Ehrenberg and J. Frank. Incorporation of aminoacyl-tRNA into the ribosome as seen by cryo-EM. *Nature Struct. Biol.* 10, 899-906 (2003).
 151. F. Tama, M. Valle, J. Frank and C.L. Brooks III. Dynamic reorganization of the functionally active ribosome explored by normal mode analysis and cryo-electron microscopy. *Proc. Natl. Acad. Sci. (USA)* 100, 9319-9323 (2003).
 152. B.K. Rath, R. Hegerl, A. Leith, T.R. Shaikh, T. Wagenknecht and J. Frank. Fast 3D motif search of EM density maps using a locally normalized cross-correlation function. *J. Struct. Biol.* 144, 95-103 (2003).
 153. R. Moccia, D. Chen, V. Lyles, E. Kapuya, Y.E.S Kalachikov, C.M.T. Spahn, J. Frank, E.R. Kandel, M. Barad and K.C. Martin. An unbiased cDNA library prepared from isolated *Aplysia* sensory neuron processes is enriched for cytoskeletal and translational mRNAs. *J. Neurosci.* 23, 9409-9417 (2003).
 154. M.G. Gomez-Lorenzo, M. Valle, J. Frank, C. Gruss, C.O.S. Sorzano, X.S. Chen, L.E. Donte and J.M. Carazo. Large T antigen on the simian virus 40 origin of replication: a 3D snapshot prior to DNA replication. *EMBO J.* 22, 6205-6213 (2003).
 155. B.K. Rath and J. Frank. Fast automatic particle picking from cryo-electron micrographs using a locally normalized cross-correlation function: a case study. *J. Struct. Biol.* 145, 84-90 (2004).
 156. C.M.T. Spahn, M.G. Gomez-Lorenzo, R.A. Grassucci, R. Jørgensen, G.R. Andersen, R. Beckmann, P.A. Penczek, J.P.G. Ballesta and J. Frank. Domain movements of elongation factor eEF2 and the eukaryotic 80S ribosome facilitate tRNA translocation. *EMBO J.* 23, 1008-1019 (2004).
 157. M. Halic, T. Becker, M.R. Pool, C.M.T. Spahn, R. Grassucci, J. Frank and R. Beckmann. Structure of the signal recognition particle interacting with the elongation arrested ribosome. *Nature* 427, 808-814 (2004).
 158. H. Gao, M. Valle, M. Ehrenberg and J. Frank. Dynamics of EF-G interaction with the ribosome explored by classification of a heterogeneous cryo-EM dataset. *J. Struct. Biol.* 147, 283-290 (2004).
 159. J. Sengupta, J. Nilsson, R. Gursky, C.M.T. Spahn, P. Nissen and J. Frank. Identification of the versatile scaffold protein RACK1 on the eukaryotic ribosome by cryo-electron microscopy. *Nat. Struct. & Mol. Biol.* 11, 957-962 (2004).
 160. M.T. Spahn, E. Jan, A. Mulder, R.A. Grassucci, P. Sarnow and J. Frank. Cryo-EM visualization of a viral internal ribosome entry site (IRES) bound to human 40S and 80S ribosomes: the IRES functions as an RNA-based translation factor. *Cell* 118, 465-475 (2004).
 161. R.K. Agrawal, M.R. Sharma, M.C. Kiel, G. Hirokawa, T.M. Booth, C.M. Spahn, R.A. Grassucci,

- A. Kaji and J. Frank. Visualization of ribosome-recycling factor on the *Escherichia coli* 70S ribosome: functional implications. *Proc. Nat. Acad. Sci. USA* 101, 8900-8905 (2004).
162. J. Nilsson, J. Sengupta, J. Frank and P. Nissen. Regulation of eukaryotic translation by the RACK1 protein: a platform for signaling molecules on the ribosome. *EMBO Reports* 5, 1137-1141 (2004).
163. J. Lei and J. Frank. Automated acquisition of cryo-electron micrographs for single particle reconstruction on an FEI Tecnai electron microscope. *J. Struct. Biol.* 150, 69-80 (2005).
164. H. Gao and J. Frank. Molding atomic structures into intermediate-resolution cryo-EM density maps of ribosomal complexes using real-space refinement. *Structure* 13, 401-406 (2005).
165. G.S. Allen, A. Zavialov, R. Gursky, M. Ehrenberg and J. Frank. The Cryo-EM Structure of a Translation Initiation Complex from *Escherichia coli*. *Cell* 121, 703-712 (2005).
166. N. Gao, A.V. Zavialov, W. Li, J. Sengupta, M. Valle, R.P. Gursky, M. Ehrenberg and J. Frank. Mechanism for the disassembly of the post-termination complex inferred from cryo-EM studies. *Mol. Cell* 18, 663-674 (2005).
167. H. Gao, M.J. Ayub, M.J. Levin and J. Frank. Structure of the 80S ribosome from *Trypanosoma cruzi* reveals novel rRNA components involved in translation initiation. *Proc. Natl. Acad. USA*, 98, 11991-11996 (2005).
168. K. Mitra, C. Schaffitzel, T. Shaikh, F. Tama, S. Jenni, C.L. Brooks, III, N. Ban and J. Frank. Structure of the *E. coli* protein-conducting channel bound to a translating ribosome. *Nature*, 438, 318-324 (2005).
169. M. Halic, T. Becker, J. Frank, C.M.T. Spahn, and R. Beckmann. Localization and dynamic behavior of ribosomal protein L30e. *Nature Struct. Mol. Biol.* 12, 467-468 (2005).
170. P.S.U. Adiga, W.T. Baxter, R.J. Hall, B. Rockel, B. Rath, J. Frank, and R.M. Glaeser. Particle picking by segmentation: a comparative study with SPIDER-based manual particle picking. *J. Struct. Biol.* 152, 211-220 (2005).
171. P.P. Datta, M.R. Sharma, L. Qi, J. Frank, and R.K. Agrawal. Interaction between the G' domain of elongation factor-G and the C-terminal domain of ribosomal protein L7/L12 during translocation, as revealed by cryo-EM. *Mol. Cell* 20, 723-731 (2005).
172. K. Mitra, C. Schaffitzel, F. Fabiola, M.S. Chapman, N. Ban, and J. Frank. Elongation arrest by SecM via a cascade of ribosomal RNA rearrangements. *Mol Cell*, in press (2006).
173. U. Rawat, H. Gao, A. Zavialov, R. Gursky, M. Ehrenberg, and J. Frank. Interactions of the release factor RF1 with the ribosome as revealed by cryo-EM. *J. Mol. Biol.*, 357, 1144-1153 (2006).
174. W. Li, Jayati Sengupta, Bimal K. Rath, and Joachim Frank. Functional conformations of the L11- ribosomal RNA complex revealed by correlative analysis of Cryo-EM and molecular dynamics simulations. *RNA*, 12, 1240-1253 (2006).
175. Kaur, R. Gillet, W. Li, R. Gursky, and J. Frank. Cryo-EM visualization of transfer-messenger RNA with two SmpBs in a stalled ribosome. *PNAS*, 103, 16484-16489 (2006).
176. J. LeBarron, Kakoli Mitra and Joachim Frank. Displaying 3D Data on RNA Secondary Structures: coloRNA. *J. Struct. Biol.*, 157, 262-270 (2007).
177. W. T. Baxter, ArDean Leith, and Joachim Frank. SPIRE: The SPIDER Reconstruction Engine. *J. Struct. Biol.*, 157, 56-63 (2006).
178. J. Fu, Haixiao Gao, and Joachim Frank. Unsupervised Classification of Single Particles by Cluster Tracking in Multi dimensional Space. *J. Struct. Biol.*, 157, 226-229 (2007).
179. H. M. Berman, S.K. Burley, Wah Chiu, Andrej Sali, Alexei Adzhubei, Philip E. Bourne, S.H. Bryant, R.L. Dunbrack, Jr., K. Fidelis, J. Frank, A. Godzik, K. Henrick, A. Joachimiak, B. Heymann, D. Jones, J.L. Markley, J. Moult, G.T. Montelione, C. Orengo, M. G. Rossmann, B. Rost, H. Saibil, T. Schwede,

- D.M. Standley, and J. D. Westbrook. Outcome of a Workshop on Archiving Structural Models of Biological Macromolecules. *Structure* 14, 1211-1217 (2006).
180. C. Yang, P. A. Penczek, A. Leith, F. J. Asturias, E. G. Ng, R. M. Glaeser, J. Frank. The parallelization of SPIDER on distributed-memory parallel computers using MPI. *J. Struct. Biol.* 157, 240-249 (2006).
 181. P. A. Penczek, C. Yang, J. Frank and C.M.T. Spahn. Estimation of variance in single particle reconstruction using the bootstrap technique. *J. Struct. Biol.*, 154, 168-183 (2006).
 182. P.A. Penczek, J. Frank and C.M.T. Spahn. A method of focused classification, based on the bootstrap 3D variance analysis, and its application to EF-G-dependent translocation. *J. Struct. Biol.* 154, 184-194 (2006).
 183. J.G. Slagter-Jäger, G.S. Allen, D. Smith, I.A. Hahn, J. Frank, and M. Belfort. Visualization of a group II intron in the 23S rRNA of a stable ribosome. *PNAS* 103, 9838-9843 (2006).
 184. K. Mitra, Joachim Frank and Arnold Driessen. Co- and post-translational translocation through the protein-conducting channel: analogous mechanisms at work. *Nat. Struct. Mol. Biol.* 13, 957-964 (2006).
 185. R. Gillet, Sukhjit Kaur, Wen Li, Marc Hallier, Brice Felden, and Joachim Frank. Scaffolding as an organizing principle in trans-translation: the roles of proteins SmpB and S1. *J. Biol. Chem.* 282, 6356-6363 (2007).
 186. S.H.W. Scheres, H. Gao, G.T. Herman, P.P.B. Eggermont, J. Frank, J.M. Carazo. Disentangling conformational states of macromolecules in 3D cryo-EM through likelihood optimization. *Nature Methods* 4, 27-29 (2007).
 187. D. J. Taylor, J. Nilsson, A. Rod Merrill, G. R. Andersen, P. Nissen, and J. Frank. GTP hydrolysis causes eEF2 to reset the ribosomal decoding center. *EMBO J.* 26, 2421–2431 (2007).
 188. J. Frank, H. Gao, J. Sengupta, N. Gao, and D. J. Taylor. The Process of mRNA-tRNA translocation. *Proc. Natl. Acad. Sci. (USA)* 50, 19671-19678 (2007).
 189. W. Li and J. Frank. Transfer RNA in the P/E hybrid state: Correlating molecular dynamics simulations with cryo-EM data. *Proc. Natl. Acad. Sci. (USA)*, 104, 16540-16545 (2007).
 190. N. Gao, A.V. Zavialov, M. Ehrenberg, and J. Frank. Specific interaction between EF-G and RRF and its implication for GTP-dependent ribosome splitting into subunits. *J. Mol. Biol.* 374, 1345-1358 (2007).
 191. H. Gao, Z. Zhou, U. Rawat, C. Huang, L. Bouakaz, C. Wang, Z. Cheng, Y. Liu, Zavialov, A., R. Gursky, S. Sanyal, M. Ehrenberg, J. Frank, and H. Song. RF3 induces ribosomal conformational changes responsible for dissociation of class I release factors. *Cell* 129, 929-941 (2007).
 192. J. LeBarron, K. Mitra, and J. Frank. Displaying 3D data on RNA secondary structures: colorRNA. *J. Struct. Biol.* 157, 262-270 (2007).
 193. Yang, C., Penczek, P.A., Leith, A., Asturias, F.J., Ng, E.G., Glaeser, R.M., and Frank, J. The parallelization of SPIDER on distributed-memory computers using MPI. *J Struct Biol* 157, 240-249 (2007).
 194. J. Nilsson, J. Sengupta, R. Gursky, P. Nissen, and J. Frank. Comparison of fungal 80S ribosomes by cryo-EM reveals diversity in structure and conformation of rRNA expansion segments. *J. Mol. Biol.* 369, 429-438 (2007).
 195. M. Marko, C. Hsieh, R. Schalek, J. Frank, and C. Mannella. Focused-ion-beam thinning of frozen-hydrated biological specimens for cryo-electron microscopy. *Nat. Methods* 4, 215-217 (2007).
 196. L.G. Trabuco, E. Villa, K. Mitra, J. Frank, and K. Schulten. Flexible fitting of atomic structures into electron microscopy maps using molecular dynamics. *Structure* 16, 673-683 (2008).

197. T.R. Shaikh, R. Trujillo, J.S. LeBarron, W.T. Baxter, and J. Frank, (2008). Particle-verification for single-particle, reference-based reconstruction using multivariate data analysis and classification. *J. Struct. Biol.* 164, 41-48.
198. J. Sengupta, J. Nilsson, J., R. Gursky, M. Kjeldgaard, P. Nissen, and J. Frank. Visualization of the eEF2-80S ribosome transition-state complex by cryo-electron microscopy. *J. Mol. Biol.* 382, 179-187 (2008).
199. J. Lebaron, R.A. Grassucci, T.R. Shaikh, W.T. Baxter, J. Sengupta, and J. Frank. Exploration of parameters in cryo-EM leading to an improved density map of the E. coli ribosome. *J. Struct. Biol.* 157, 262-270. (2008).
200. L.G. Trabuco, E. Villa, K. Mitra, J. Frank, and K. Schulten. Flexible fitting of atomic structures into electron microscopy maps using molecular dynamics. *Structure* 16, 673-683 (2008).
201. X. Agirrezabala, J. Lei, J.L. Brunelle, R.F. Ortiz-Meoz, R. Green, and J. Frank. Visualization of the hybrid state of tRNA binding promoted by spontaneous ratcheting of the ribosome. *Mol. Cell* 32, 190-197 (2008).
202. W.T. Baxter, R.A. Grassucci, H. Gao, and J. Frank. Determination of signal-to-noise ratios and spectral SNRs in cryo-EM low-dose imaging of molecules. *J. Struct. Biol.* 166, 126-132 (2009).
203. E. Villa, J. Sengupta, L.G. Trabuco, J. LeBarron, W.T. Baxter, T.R. Shaikh, R.A. Grassucci, P. Nissen, M. Ehrenberg, K. Schulten, and J. Frank, J. Ribosome-induced changes in elongation factor Tu conformation control GTP hydrolysis. *Proc. Natl. Acad.Sci. USA* 106, 1063-1068 (2009).
204. Taylor, D., Devkota, B., Huang, A.D., Topf, M., Narayanan, E., Sali, A., Harvey, S.C., and Frank, J. Comprehensive molecular structure of the eukaryotic ribosome. *Structure* 17, 1591-1604 (2009).
205. M. Sorci, R.A. Grassucci, I. Hahn, J. Frank, and G. Belfort. Time-dependent insulin oligomer reaction pathway prior to fibril formation: cooling and seeding. *Proteins* 77, 62-73(2009).
206. J. Sengupta, A. Johnson, and J. Frank, J. Characterization of the nuclear export adaptor protein Nmd3 in association with the 60S ribosomal subunit. *J. Cell Biol.* 189, 1079-1086 (2010).
207. H. Liao and J. Frank, J. Classification by bootstrapping in single-particle methods. In: *From Nano to macro. Proc. IEEE International Symposium on Biomedical Imaging*, 169-172 (2010).
208. K. Reblova, W. Li, H. Gao, J. Frank, and J. Sponer. Dynamics of the base of ribosomal A- site finger revealed by molecular dynamics simulations and cryo-EM. *Nucl. Acids Res.* 38, 1325-1340 (2010).
209. W. Li, L.G. Trabuco, K. Schulten, and J. Frank. Molecular dynamics of EF-G during translocation. *Proteins* 79, 1478-1486 (2011).
210. J. Sengupta, C. Bussiere, J. Pallesen, M. West, A. Johnson, and J. Frank. Characterization of the nuclear export adaptor protein Nmd3 in association with the 60S ribosomal subunit. *J. Cell Biol.* 7, 1079-1086 (2010).
211. T. Huang, T.R. Shaikh, K. Gupta, L.M. Contreras-Martin, R.A. Grassucci, G.D. Van Duyne, J. Frank, and M. Belfort. The group II intron ribonucleo-protein precursor is a large, loosely packed structure. *Nucl. Acids Res.* 39, 2845-2854 (2011).
212. Langlois, R. and Frank, J. A clarification of the terms used in comparing semi-automated particle selection algorithms in cryo-EM. *J. Struct. Biol.* 175, 348-352 (2011).
213. J. Fu, J.B. Munro, S.C. Blanchard, and J. Frank. Cryo-EM structures of the ribosome complex in intermediate states during tRNA translocation. *Proc. Natl. Acad. Sci. USA* 108, 4817-4821 (2011)
214. X. Agirrezabala, E. Schreiner, L.G. Trabuco, J. Lei, R.F. Ortiz-Meoz, K. Schulten, R. Green, and J. Frank. Structural insights into cognate vs. near-cognate discrimination during decoding.

- EMBO J. 30, 1497-1507 (2011).
215. R. Langlois, J. Pallesen, and J. Frank. Reference-free particle selection enhanced with semi-supervised machine learning for cryo-electron microscopy. *J. Struct. Biol.* 175, 353-361 (2011).
 216. X. Agirrezabala, H. Liao, E. Schreiner, J. Fu, R.F. Ortiz-Meoz, K. Schulten, R. Green, R., and J. Frank. Structural characterization of mRNA-tRNA translocation intermediates. *Proc. Natl. Acad. Sci. USA* 109, 6094-6099 (2012).
 217. R. Henderson, A. Sali, M.L. Baker, B. Carragher, B. Devkota, K.H. Downing, E.H. Egelman, Z. Feng, J. Frank, N. Grigorieff, W. Jiang, S.J. Ludtke, O. Medalia, P.A. Penczek, P.B. Rosenthal, M.G. Rossmann, M.F. Schmid, G.F. Schröder, A.C. Steven, D.L. Stokes, J.D. Westbrook, W. Wrighers, H. Yang, J. Young, H. M. Berman, W. Chiu, G.J. Kleywegt, and C.L. Lawson. Outcome of the First Electron Microscopy Validation Task Force Meeting. *Structure* 20, 206-214 (2012).
 218. C. Bussiere, Y. Hashem, S. Arora, J. Frank, and A.W. Johnson. Integrity of the P-site is probed during maturation of the 60S ribosomal subunit. *J. Cell Biol.* 6, 747-759 (2012).
 219. D. Taylor, A. Unbehaun, W. Li, S. Das, J. Lei, H.Y. Liao, R.A. Grassucci, T.V. Pestova, and J. Frank. Cryo-EM structure of the mammalian eukaryotic release factor eRF1/eRF associated termination complex. *Proc. Natl. Acad. Sci. USA* 109, 18413-18418 (2012).
 220. Y. Hashem, A. des Georges, J. Fu, S.N. Buss, F. Jossinet, A. Jobe, Q. Zhang, H.Y. Liao, R.A. Grassucci, C. Bajaj, E. Westhof, S. Madison-Antenucci, and J. Frank. High-resolution cryo-EM structure of *Trypanosoma brucei* eukaryotic ribosome. *Nature* 494, 385-389 (2013).
 221. W. Li, G.C. Atkinson, N.S. Thakor, U. Allas, C. Lu, K. Chan, T. Tenson, K. Schulten, K.S. Wilson, V. Hauryliuk, and J. Frank. Mechanism of tetracycline resistance by ribosomal protection protein Tet(O). *Nature Comm.* 4, 1477 doi:10.1038/ncomms2470 (2013).
 222. G. Sharma, J. Pallesen, S. Das, R.A. Grassucci, R. Langlois, C.M. Hampton, D.F. Kelly, A. des Georges, and J. Frank. Affinity grid-based cryo-EM of PKC binding to RACK1 on the ribosome. *J. Struct. Biol.* 181, 190-194 (2013).
 223. J. Pallesen, J., Y. Hashem, G. Korkmaz, R. Koripella, C. Huang, M. Ehrenberg, S. Sanya, and J. Frank. Cryo-EM visualization of the ribosome in termination complex with apo-RF3 and RF1. *eLife* 2013;2:e00411.
 224. Y. Hashem, A. des Georges, V. Dhote, R. Langlois, H.L. Liao, R.A. Grassucci, C.U.T. Hellen, T.V. Pestova, and J. Frank. Structure of the mammalian ribosomal 43S preinitiation complex bound to the scanning factor DHX29. *Cell* 153, 1108-1119 (2013).
 225. Y. Hashem, A. des Georges, V. Dhote, R. Langlois, H.Y. Liao, R.A. Grassucci, T.V. Pestova, C.U. Hellen, and J. Frank.). Hepatitis-C-virus-like internal ribosome entry sites displace eIF3 to gain access to the 40S subunit. *Nature* 503, 539-543 (2013).
 226. A. des Georges, Y. Hashem, A. Unbehaun, R.A. Grassucci, D. Taylor, C.U.T. Hellen, T.V. Pestova, and J. Frank. Structure of the mammalian ribosomal pre-termination complex associated with eRF1•eRF3•GDPNP. *Nucl. Acids Res.* 42, 3409-3418 (2013).
 227. G. Boël, P.C. Smith, W. Ning, M.T. Englander, B. Chen, Y. Hashem, A.J. Testa, J.J. Fischer, H.-J. Wieden, J. Frank, R.L. Gonzalez, and J.F. Hunt. The ABC-F protein EttA gates ribosome entry into the translation elongation cycle. *Nat. Struct. Mol. Biol.* 21, 143-151 (2014).
 228. B. Chen, G. Boël, Y. Hashem, W. Ning, J. Fei, C. Wang, R.L. Gonzalez, J.F. Hunt, and J. Frank. EttA regulates translation by binding to the ribosomal E site and restricting ribosome-tRNA dynamics. *Nat. Struct. Mol. Biol.* 21, 152-159 (2014).
 229. R. Langlois, J. Pallesen, J.T. Ash, D.N. Ho, J.L. Rubinstein, and J. Frank. Automated particle picking for low-contrast macromolecules in cryo-electron microscopy. *J Struct Biol.* 186, 1-7 (2014).
 230. B. Chen, B. Shen, and J. Frank. Particle migration analysis in iterative classification of cryo-EM

- single-particle data. *J Struct Biol* **188**, 267-273. (2014).
231. A. Dashti, P. Schwander, R. Langlois, R. Fung, W. Li, A. Hosseinizadeh, H.Y. Liao, J. Pallesen, G. Sharma, V.A. Stupina, A.E. Simon, J. Dinman, J. Frank, and A. Ourmazd. Trajectories of the ribosome as a Brownian nanomachine. *Proc Natl Acad Sci U S A* **111**, 17492-17497 (2014).
 232. R. Zalk, O.B. Clarke, A. des Georges, R.A. Grassucci, S. Reiken, F. Mancina, W.A. Hendrickson, J. Frank, and A.R. Marks. Structure of a mammalian ryanodine receptor. *Nature* **517**, 44–49 (2015).
 233. C.D. Kinz-Thompson, A.K. Sharma, J. Frank, R.L. Gonzalez, and D. Chowdhury. Quantitative connection between ensemble thermodynamics and single-molecule kinetics: a case study using cryo-EM and smFRET investigations of the ribosome. *J Phys Chem B* **119**, 10888-10901 (2015).
 234. H.Y. Liao, Y. Hashem, and J. Frank. Efficient estimation of three-dimensional covariance and its application in the analysis of heterogeneous samples in cryo-electron microscopy. *Structure* **23**, 1129–1137 (2015).
 235. W. Li, Z. Liu, R.K. Koripella, R. Langlois, S. Sanyal, and J. Frank, J. Activation of GTP hydrolysis in mRNA-tRNA translocation by Elongation Factor G. *Science Adv.* **4** No. 1 e1500169 (2015).
 236. B. Chen, S. Kaledhonkar, M. Sun, B. Shen, Z. Lu, D. Barnard, T. Lu, R.L. Gonzalez, and J. Frank, J. Structural dynamics of ribosome subunit association studied by mixing-spraying time-resolved cryo-EM. *Structure* **23**, 1097–1105 (2015).
 237. R. Marabini, B. Carragher, S. Chen, J. Chen, A. Cheng, K.H. Downing, J. Frank, R.A. Grassucci, J.B. Heymann, W. Jiang, S. Jonic, H.Y. Liao, S.J. Ludtke, S. Patwari, A.L. Piotrowski, A. Quintana, C.O.S. Sorzano, H. Stahlberg, J.Vargas, N.R.Voss, W. Chiu, and J.M. Carazo. CTF challenge: Result summary. *J. Struct. Biol.* **190**, 348–359 (2015).
 238. A. Des Georges, V. Dhote, L. Kuhn, C.U. Hellen, T.V. Pestova, J. Frank, and Y. Hashem. Structure of mammalian eIF3 in the context of the 43S preinitiation complex. *Nature* **525**, 491–495 (2015).
 239. M. Sun, W. Li, K. Blomqvist, S. Das, Y. Hashem, J.D. Dvorin, and J. Frank. Dynamical features of the *Plasmodium falciparum* ribosome during translation. *Nucl. Acids Res.* **43**, 10515-10524 (2015).
 240. E.C. Twomey, M.V. Velshanskaya, R.A. Grassucci, J. Frank, and A.I. Sobolevsky. Elucidation of AMPA receptor–stargazin complexes by cryo–electron microscopy. *Science* **353**, 83-86 (2016).
 241. A. Des Georges, O.B. Clarke, R. Zalk, Q. Yuan, K.J. Condon, R.A. Grassucci, W.A. Hendrickson, A.R. Marks, and J. Frank. Structural basis for gating and activation of RyR1, *Cell*, in press. (2016).

CHAPTERS IN BOOKS

1. J. Frank. Computer processing of electron micrographs. In: *Advanced Techniques in Biological Electron Microscopy* (J. Koehler, ed.) Springer Verlag Heidelberg, 1973, pp. 215-274.
2. J. Frank. Use of anomalous scattering for element discrimination. In: *Image Processing and Computer-Aided Design in Electron Optics* (P. Hawkes, ed.) Academic Press, New York, 1973, pp 196-211 (1973).
3. J. Frank. The role of correlation techniques in computer image processing. In: *Computer Processing of Electron Micrographs* (P.W. Hawkes, ed.) Springer Verlag Heidelberg, 1980, pp. 187-222.
4. J. Frank. Introduction to quantitative methods of reconstruction. In: *Methods and Perspectives in Cell Biology: Three-Dimensional Ultra-Structure in Biology*, Vol. XXVI (J.N. Turner, ed.) Academic Press, NY, 1980, pp. 199-213.

5. J. Frank. Three-dimensional reconstruction of single molecules. In: *Methods and Perspectives in Cell Biology: Three-Dimensional Ultrastructure in Biology*, Vol. XXVI (J.N. Turner, ed.) Academic Press, NY, 1980, pp. 325-344.
6. J. Frank, A. Verschoor and T. Wagenknecht. Computer processing of electron-microscopic images of single macromolecules. In: *New Methodologies in Studies of Protein Conformation* (T.T. Wu, ed.) Von Nostrand Reinhold, Inc., NY, 1985, pp. 36-89.
7. J. Frank and M. Radermacher. Three-dimensional reconstruction of biomolecular assemblies. In: *Advanced Techniques in Biological Electron Microscopy* (J. Koehler, ed.) Springer Verlag Berlin, 1986, pp. 1-72.
8. J. Frank, M. Radermacher, T. Wagenknecht and A. Verschoor. Methods for studying ribosome structure by electron microscopy and computer image processing. In: *Methods in Enzymology* (K. Moldave, ed.) Academic Press, NY, 1988, pp. 3-35.
9. J. Frank. Introduction. In: *Electron Tomography* (J. Frank, ed.) Plenum, NY, 1992, pp. 1-13.
10. J. Frank and B.F. McEwen. Alignment by cross-correlation. In: *Electron Tomography* (J. Frank, ed.) Plenum, NY, 1992, pp. 205-213.
11. J. Frank, R.K. Agrawal and A. Verschoor. The structure of the ribosome. In: *Encyclopedia of Life Sciences*, Macmillan Press, 2000, Article No. A534, <http://www.els.net/elsonline/html/A0000534.html>.
12. J. Frank and R.K. Agrawal. Bacterial ribosomes. In: *Encyclopedia of Life Sciences*, Macmillan Press, 2000, Article No. A305, <http://www.els.net/elsonline/html/A0000305.html>.
13. J. Frank, P. Penczek, R.A. Grassucci, A. Heagle, C.M.T. Spahn and R.K. Agrawal. Cryo-electron microscopy of the translational apparatus: Experimental evidence for the paths of mRNA, tRNA, and the polypeptide chain. In: *The Ribosome: Structure, Function, Antibiotics, and Cellular Interactions* (R.A. Garrett, S.R. Douthwaite, A. Liljas, A.T. Matheson, P.B. Moore, H.F. Noller, eds.) ASM Press, Washington, DC, 2000.
14. J. Frank, P. Penczek, R.K. Agrawal, R.A. Grassucci and A.B. Heagle. Three-dimensional cryoelectron microscopy of ribosomes. In: *Methods of Enzymology* (D.W. Celander and J.N. Abelson, eds.) Academic Press, San Diego, CA, 2000, Ch. 18, pp. 276-291.
15. J. Frank and R.K. Agrawal. Ratchet-like movements between the two ribosomal subunits: their implications in elongation factor recognition and tRNA translocation. In: *Cold Spring Harbor Symposia on Quantitative Biology*, Vol. LXVI, Cold Spring Harbor Press, NY, 2001, pp. 67-75.
16. R. Beckmann, C.M.T. Spahn, J. Frank and G. Blobel. The active 80S ribosome-Sec61 complex. In: *Cold Spring Harbor Symposia on Quantitative Biology*, Vol. LXVI, Cold Spring Harbor Press, NY, 2001, pp. 543-554.
17. J. Frank. The dynamics of the ribosome as inferred by cryo-EM: induced and self-organized motions. In: *Conformational Proteomics of Macromolecular Architectures*, World Scientific Publishing, Singapore, 2004.
18. J. Sengupta and J. Frank. Cryo-electron microscopy as a tool to study molecular machines. In *Protein Structures: Methods in Protein Structure and Stability Analysis*, Nova Science Publishers, Inc., Hauppauge, NY (2006).
19. P.A Penczek and J. Frank. Resolution in Electron Tomography. In "Electron Tomography," ed. J. Frank, Springer Verlag, New York (2006).
20. D. J Taylor, J. Frank, and T.G. Kinzy, Structure and function of the Eukaryotic Ribosome and Elongation Factors. In "Translational Control in Biology and Medicine" (Cold Spring Harbor Monograph Series 48) Eds. M.B. Mathews, N. Sonenberg, and J.W.B. Hersey, Cold Spring Harbor Press (2007).
21. H. Gao, J. LeBarron, and J. Frank. Ribosomal dynamics: intrinsic instability of a molecular machine. In *Non-Protein Coding RNAs*, N.G. Walter, S.A. Woodson, and R.T. Batey, eds. (Springer-Verlag Berlin), pp. 303-316 (2009).

22. A. Leith, W.T. Baxter, and J. Frank. Use of SPIDER and SPIRE in Image Reconstruction. In *International Tables for Crystallography*, M.G. Rossmann, Arnold, E., Himmel, D.M., ed (2010).
23. J. Frank. Ribosome dynamics: Progress in the characterization of mRNA-tRNA translocation by cryo-electron microscopy. In *Ribosomes: Structure, Function, and Dynamics*, M. Rodnina, Wintermeyer, W., Green, R., ed. Springer (2011).
24. J. Frank. Exploring the Dynamics of Supramolecular Machines with Cro-Electron Microscopy. In *New Chemistry and New Opportunities from the Expanding Protein Universe*, K. Wüthrich, I.A. Wilson, D. Hilvert, D.W. Wolan, and A. De Wit, eds. World Scientific, pp. 313–317 (2014).
25. A. des Georges, Y. Hashem, S.N. Buss, F. Jossinet, Q. Zhang, H.Y. Liao, J. Fu, A. Jobe, R.A. Grassucci, R. Langlois, C. Bajaj, E. Westhof, S. Madison-Antenucci, and J. Frank. High-Resolution Cryo-EM Structure of the Trypanosoma brucei Ribosome – a Case Study. In *Computational Methods for Three-Dimensional Microscopy Reconstruction*, G.T. Herman, and J. Frank, eds. Springer, pp. 97-132 (2014).
26. B. Shen, B. Chen, H. Liao, and J. Frank. Quantitative Analysis in Iterative Classification Schemes for Cryo-EM Application. In *Computational Methods for Three-Dimensional Microscopy Reconstruction*, G.T. Herman, and J. Frank, eds. Springer, pp. 67-95 (2014).
27. R. Langlois, J.T. Ash, J. Pallesen, and J. Frank. Fully Automated Particle Selection and Verification in Single-Particle Cryo-EM. In *Computational Methods for Three-Dimensional Microscopy Reconstruction*, G.T. Herman, and J. Frank, eds. Springer, pp. 43-66 (2014).

BOOKS

1. “Electron Tomography”, ed. J. Frank, Plenum Publishing Corp., New York, 1992.
2. “Three-dimensional Electron Microscopy of Macromolecules”. J. Frank, Academic Press, San Diego, 1996.
3. “Three-dimensional Electron Microscopy of Macromolecules”. J. Frank, Oxford University Press, New York, 2006.
4. “Electron Tomography”, II Edition, ed. J. Frank, Springer Verlag, New York, 2006.
5. “Electron Crystallography of Biological Macromolecules”, R.M. Glaeser, K. Downing, W. Chiu, J. Frank, D. DeRosier, Oxford University Press, New York, 2006.
6. “Molecular Machines in Biology – Workshop of the Cell,” ed. J. Frank, Cambridge University Press, New York 2011.
7. “Found in Translation – Collection of Original Articles on Single-Particle Reconstruction and the Structural Basis of Protein Synthesis”, ed. J. Frank, World Scientific Press, Singapore 2013.
8. “Computational Methods for Three-Dimensional Microscopy Reconstruction,” eds. G. Herman and J. Frank, Birkhaeser/Springer, New York 2014.

INVITED PAPERS

1. J. Frank. Use of anomalous scattering for element discrimination. In: *Image Processing and Computer-aided Design in Electron Optics* (P.W. Hawkes, ed.) Academic Press, pp. 196-211 (1973).
2. J. Frank. Report on OSA topical meeting on image processing, Stanford University, Aug. 1975, *Appl. Optics* 14, 2782-2784 (1975).
3. J. Frank. Optimum use of image information using signal detection and averaging techniques. *Am. NY Acad. Sci.* 306, 112-120 (1978).
4. W. Goldfarb, J. Frank, M. Kessel, J.C. Hsung, C.H. Kim and T.E. King. Cytochrome oxidase

- vesicles with two-dimensional order. Intl. Symp. Cytochrome Oxidase. Mt. Rokossan, Kobe, Japan. Elsevier, Amsterdam and New York (1978).
5. J. Frank. Image analysis in electron microscopy. *J. Microscopy* 117, 25-38 (1979).
 6. J. Frank and W. Goldfarb. Methods of averaging of single molecules and lattice fragments. In: *Electron Microscopy at Molecular Dimensions. State of the Art and Strategies for the Future.* (W. Baumeister, ed.) Springer Berlin, pp. 261-269 (1980).
 7. M. Kessel, J. Frank and W. Goldfarb. Low-dose electron microscopy of individual biological macromolecules. In: *Electron Microscopy at Molecular Dimensions. State of the Art and Strategies for the Future* (W. Baumeister, ed.) Springer Berlin, pp. 154-160 (1980).
 8. M. van Heel and J. Frank. Classification of particles in noisy electron micrographs by using correspondence analysis. In: *Pattern Recognition in Practice* (E.S. Gelsema and L. Kanal, eds.) North Holland, Amsterdam, pp. 235-245 (1980).
 9. J. Frank. Differential averaging of single molecule images using multivariate statistical classification. Proc. 40th Ann. Meeting EMSA, 706-709 (1982).
 10. J. Frank and M. van Heel. Averaging techniques and correspondence analysis. Hamburg 1, Vol. I, 107-114 (1982).
 11. J. Frank. The role of multivariate image analysis in solving the architecture of the *Limulus polyphemus* hemocyanin molecule. *Ultramicroscopy* 13, 153-164 (1984).
 12. J. A. Subirana, S. Munoz-Guerra, M. Radermacher and J. Frank. Three-dimensional reconstruction of chromatin fibers. *J. Biomol. Str. Dyns.* 1, 705-714 (1983).
 13. C. Mannella and J. Frank. Negative staining characteristics of arrays of mitochondrial pore protein: Use of multivariate statistical analysis to classify diffraction patterns. *Ultramicroscopy* 13, 93-102 (1984).
 14. J. Frank. Quantitative study of macromolecular assemblies with the aid of correlation alignment, multivariate image analysis, and three-dimensional reconstruction. 8th Int. Biophysics Congress, Bristol, p. 167 (1984).
 15. J. Frank. Recent advances of image processing in the structural analysis of biological macromolecules. 8th Europ. Congr. El. Microsc., Budapest 2, 1307-1316 (1984).
 16. M. Boublik, G.T. Oostergetel, J.S. Wall, J.F. Hainfeld, M. Radermacher, T. Wagenknecht, A. Verschoor and J. Frank. Structure of ribosomes and their components by advanced techniques of electron microscopy and computer image analysis. In: *Structure, Function and Genetics of Ribosomes* (B. Hardesty and G. Kramer, eds.) Springer-Verlag, NY, 1986, pp. 68-86.
 17. J. Frank, M. Radermacher, T. Wagenknecht and A. Verschoor. A new method for 3-D reconstruction of single macromolecules using low-dose electron micrographs. *Ann. NY Acad. Sci.* 483, 77-87 (1986).
 18. J. Frank, B.F. McEwen, M. Radermacher and C.L. Rieder. Methods for three-dimensional reconstruction of cellular components within a thick section. Proc. 44th Ann. Mtg EMSA, pp. 18-21 (1986).
 19. J. Frank, B. McEwen, M. Radermacher, J.N. Turner and C.L. Rieder. Three dimensional tomographic reconstruction in high-voltage electron microscopy. Proc. 11th Int. Congr. Electron Microscopy Kyoto 2, 1145-1150 (1986).
 20. J. Frank and C. Mannella. New avenues in electron microscopy of transmembraneous biomolecular assemblies. In: *Advances in Membrane Biochemistry and Bioenergetics* (Ch. Kim et. al., eds.) Plenum, 1987, pp. 459-467.
 21. J. Frank, B. McEwen, M. Radermacher, J.N. Turner and C.L. Rieder. Three-dimensional reconstruction in high-voltage electron microscopy. *J. Electron Microsc. Tech.* 6, 193-205 (1987).
 22. J. Frank, A. Verschoor, T. Wagenknecht, M. Radermacher and J-M. Carazo. A new non-crystallographic image-processing technique reveals the architecture of ribosomes. *Trends Biochem. Sciences* 13, 123-127 (1988).
 23. J. Frank. Image analysis of single macromolecules. *Electron Microscopy Reviews* 2, 53-74 (1989).

24. J. Frank. Three-dimensional imaging techniques in electron microscopy. *BioTechniques* 7, 164-173 (1989).
25. J. Frank. Classification of macromolecular assemblies studied as "single particles". *Quart. Rev. Biophys.* 23, 281-329 (1990).
26. J. Frank, A. Verschoor, M. Radermacher and T. Wagenknecht. Morphologies of eubacterial and eukaryotic ribosomes as determined by three-dimensional electron microscopy. In: *The Ribosome* (W.E. Hill, A. Dahlberg, R.A. Garrett, P.B. Moore, D. Schlessinger, J.R. Warner, eds.), American Society for Microbiology, Washington, DC, 1990, pp. 107-113.
27. J.N. Turner, J. Frank and C.L. Rieder. Biological Microscopy and Image Reconstruction Resources, *EMSA Bulletin* 20, 127-130 (1990).
28. J. Frank and M. Radermacher. Three-dimensional reconstruction of single particles negatively stained or in vitreous ice. *Ultramicroscopy* 46, 241-262 (1990). (Proc. Workshop on Quantitative Electron Microscopy, Schloss Ringberg, Rottach-Egern, Germany (Dec. 2-7, 1991).)
29. J. Frank, P. Penczek and W. Liu. Alignment, classification, and 3-D reconstruction of single particles embedded in ice. Proc. X Pfefferkorn Conference on Image and Signal Processing (P.W. Hawkes and W.O. Saxton, eds.) *Scanning Suppl.* 6, pp. 11-22 (1992).
30. J. Frank. Three-dimensional reconstruction at the molecular level. *Microscopy, Microanalysis, Microstructures* 3, 45-54 (1992).
31. J. Frank, W. Chiu and R. Henderson. Flopping polypeptide chains and SULEIKA's subtle imperfections: analysis of variations in the electron micrograph of purple membrane. *Ultramicroscopy* 49, 387-396 (1993).
32. A. Verschoor, S. Srivastava, M. Radermacher, J. Frank, R. Traut, M. Stöffler-Meilicke and D. Glitz. Functional site determinations in three dimensions on eukaryotic and eubacterial ribosomes. In: *The Translational Apparatus* (K.H. Nierhaus et al., eds.) Plenum Press, NY 1993.
33. J. Frank, A. Verschoor, Y. Li, J. Zhu, R.K. Lata, M. Radermacher, P. Penczek, R. Grassucci, R. K. Agrawal and S. Srivastava. A model of the translational apparatus based on three-dimensional reconstruction of the *E. coli* ribosome. *Biochem. Cell Biol.* 73, 757-765 (1995).
34. J. Frank. Approaches to large-scale structures. *Curr. Opin. Struct. Biol.* 5, 194-201 (1995).
35. J. Frank. How the ribosome works. *Amer. Sci.* 86, 428-439 (1998).
36. J. Frank. The ribosome - structure and functional ligand-binding experiments using cryo-electron microscopy. *J. Struct. Biol.* 124, 142-150 (1998).
37. R.K. Agrawal, R.K. Lata and J. Frank. Conformational variability in *Escherichia coli* 70S ribosome as revealed by 3D cryo-electron microscopy. *Intern. J. Biochem. Cell Biol.* 31, 243-254 (1999).
38. R.A. Agrawal and J. Frank. Structural studies of the translational apparatus. *Curr. Opin. Struct. Biol.* 9, 215-221. (1999)
39. R.K. Agrawal, R.K. Lata and J. Frank. Conformational variability in *Escherichia coli* 70S ribosome as revealed by 3D cryo-electron microscopy. *Intern. J. Biochem. Cell Biol.* 31, 243-254 (1999).
40. P. Penczek, N. Ban, R.A. Grassucci, R.K. Agrawal and J. Frank. *Haloarcula marismortui* 50S subunit-complementarity of electron microscopy and X-ray crystallographic information. *J. Struct. Biol.* 128, 44-50 (1999).
41. A. Malhotra and J. Frank. Predicting three-dimensional structure of ribosomal RNA using cryo electron microscopy maps of the *Escherichia coli* ribosome. *Nucleic Acids Symp. Series* 41, 32-34 (1999).
42. J. Frank. The ribosome – a macromolecular machine par excellence. *Chemistry & Biology* 7, R133-R141 (2000).
43. J. Frank, P. Penczek, R.K. Agrawal, R.A. Grassucci and A.B. Heagle. Three-dimensional cryoelectron microscopy of ribosomes. *Methods Enzymol.* 317, 276-291 (2000).

44. J. Frank, P. Penczek, R.A. Grassucci, A. Heagle, C.M.T. Spahn and R.K. Agrawal. Cryo-electron microscopy of the translational apparatus: Experimental evidence for the paths of mRNA, tRNA, and the polypeptide chain. In: *The Ribosome: Structure, Function, Antibiotics, and Cellular Interactions* (R.A. Garrett, S.R. Douthwaite, A. Liljas, A.T. Matheson, P.B. Moore, and H.F. Noller, eds.) ASM Press, Washington, DC, 2000.
45. R.K. Agrawal, A.B. Heagle and J. Frank. Studies of elongation factor G-dependent tRNA translocation by three-dimensional cryo-electron microscopy. In: *The Ribosome: Structure, Function, Antibiotics, and Cellular Interactions* (R.A. Garrett, S.R. Douthwaite, A. Liljas, A.T. Matheson, P.B. Moore and H.F. Noller, eds.) ASM Press, Washington, DC, 2000, Ch.6, pp. 53-62.
46. M.S. VanLoock, A. Malhotra, D.A. Case, R.K. Agrawal, P. Penczek, T.R. Easterwood, J. Frank, and S. C. Harvey. Functional interpretation of the cryo-electron microscopy map of the 30S ribosomal subunit from *Escherichia coli*. In: *The Ribosome: Structure, Function, Antibiotics, and Cellular Interactions* (R.A. Garrett, S.R. Douthwaite, A. Liljas, A.T. Matheson, P.B. Moore, and H.F. Noller, eds.) ASM Press, Washington, DC, 2000, Ch.15, pp. 165-171.
47. J. Frank. Cryo-electron microscopy as an investigative tool: the ribosome as an example. *BioEssays* 23, 725-732 (2001).
48. J. Frank. Ribosomal dynamics explored by cryo-electron microscopy. *Methods* 25, 309-315 (2001).
49. J. Frank. Single-particle imaging of macromolecules by cryo-electron microscopy. *Ann. Rev. Biophys. Biomol. Struct.* 31, 303-319 (2002).
50. J. Frank. A cold look at transcription. *Structure* 10, 1156-1157 (2002).
51. J. Frank, T. Wagenknecht, B.F. McEwen, M. Marko, C. Hsieh and C.A. Mannella. Three-dimensional imaging of biological complexity. *J. Struct. Biol.* 138, 85-91 (2002).
52. J. Frank. Electron microscopy of functional ribosome complexes. *Biopolymers* 68, 223-233 (2003).
53. J. Frank. Toward an understanding of the structural basis of translation. *Genome Biology* 4, 237 (2003).
54. J. Frank. The dynamics of the ribosome as inferred by cryo-EM: induced and self-organized motions. In *Conformational Proteomics of Macromolecular Architecture*. R.H.Cheng & L.Hammar, Eds., (World Scientific Publishing Co.) (2004).
55. J. Frank, J. Sengupta, H. Gao, W. Li, M. Valle, A. Zavialov and M. Ehrenberg. The role of tRNA as a molecular spring in decoding, accommodation, and peptidyl transfer. *FEBS Lett.* 579, 959-962 (2005).
56. K. Mitra and J. Frank. Ribosome dynamics: insights from atomic structure modeling into cryo-electron microscopy maps. *Ann. Rev. Biophys. Biomolecular Struct.*, 35, 299-317 (2006).
57. D.J. Taylor, J. Frank and T.G. Kinzy. Structure and function of the eukaryotic ribosome and elongation factors. In *Translational Control in Biology and Medicine*, M.B. Mathews, N. Sonenberg, and J.W.B. Hershey, eds. (Cold Spring Harbor Press), pp. 59-86.
58. J. Frank and C.M.T. Spahn. The Ribosome and the mechanism of protein synthesis. *Rep. Progr. Phys.* 69, 1383-1417 (2006).
59. N. Gao and J. Frank. A library of RNA bridges. *Nature Chem. Biol.* 2, 231-232 (2006).
60. G. Allen and J. Frank. Structural insights on the translation initiation complex: Ghosts of a universal initiation complex. *Mol. Microbiol.* 63, 941-950 (2007).
61. R.A. Grassucci, D.J. Taylor, and Frank, J. Preparation of macromolecular complexes for cryo-electron microscopy. *Nat. Protoc.* 2, 3239-3246 (2007).
62. R.A. Grassucci, D. Taylor, and J. Frank. Visualization of macromolecular complexes using cryo-electron microscopy with FEI Tecnai transmission electron microscopes. *Nat. Protoc.* 3, 330-339 (2008).

63. T.R. Shaikh, H. Gao, W.T. Baxter, F.J. Asturias, N. Boisset, A. Leith, and J. Frank, J. SPIDER image processing for single-particle reconstruction of biological macromolecules from electron micrographs. *Nat. Protoc.* 3, 1941-1974 (2008).
64. J. Frank. Single-particle reconstruction of biological macromolecules in electron microscopy – 30 years. *Q. Rev. Biophys* 42, 139-158 (2009).
65. X. Agirrezabala and J. Frank. Elongation in translation as a dynamic interaction among the ribosome, tRNA, and elongation factors EF-G and EF-Tu. *Quart. Rev. Biophys.* 42, 159-200 (2009).
66. J. Frank and R.L. Gonzales. Structure and dynamics of a processive Brownian motor: the translating ribosome. *Ann. Rev. Biochem.* 79, 381-412 (2010).
67. X. Agirrezabala, and J. Frank. From DNA to proteins via the ribosome. Structural insights into the workings of the translation machinery. *Human Genomics* 4, 226-237 (2010).
68. J. Fu, Y. Hashem, J. Wower, and J. Frank. tmRNA on its way through the ribosome: Two steps of resume, and what next? *RNA Biol* 8, 586-590 (2011).
69. H. Liao and J. Frank. Definition and estimation of resolution in single-particle reconstructions. *Structure* 18, 768-775 (2010).
70. J. Frank. Intermediate states during mRNA-tRNA translocation. *Cur. Opin. Struct. Biol.* 22, 1-8 (2012).
71. Frank, J. (2013). Story in a Sample – the Potential (and Limitations) of Cryo-Electron Microscopy Applied to Molecular Machines. *Biopolymers* 99, 832-836.
72. B. Chen, and J. Frank, J. Two promising future developments of cryo-EM: capturing short-lived states and mapping a continuum of states of a macromolecule. *Microscopy*, 1–11 (2015).
73. J. Frank, J. Generalized single-particle cryo-EM – a historical perspective. *Microscopy*. (2015).
74. J. Frank. Whither ribosome structure and dynamics research? (A Perspective). *J. Mol. Biol.* (2016).
75. J. Frank, and A. Ourmazd. Continuous changes in structure mapped by manifold embedding of single-particle data in cryo-EM. *Methods* 100, 61-67 (2016).

F. Invitations (since 1980)

INVITATIONS SINCE 1980

April 14-16, 1980	Technical Academy, Esslingen, W. Germany. Course on image quality analysis in electron microscopy: “Averaging Methods for Non-Periodic Objects Imaged with Low Dose.”
April 1980	Max-Planck Institute for Biophysical Chemistry, Goettingen, W. Germany Invitation for a two-week consultation visit.
May 1980	Lecture at the Fritz-Haber Institute der Max-Planck-Gesellschaft in Berlin, Germany.
August 21-23, 1980	Biozentrum Basel Switzerland - Invitation for three days of consultation.
August 24-29, 1980	European Congress of Electron Microscopy, The Hague, Netherlands. Citation as a highlight of the Congress: “Intelligent Averaging of Molecules Using Computer Alignment and Correspondence Analysis” (together with Marin van Heel).
June 1981	Lectures at the University of Groningen, The Hadassah Medical School in Jerusalem, and the Weizmann Institute of Science in Rehovot.
July 1981	Duke Marine Biology Laboratory, North Carolina: “Single-Particle Averaging and Correspondence Analysis.”
Fall 1981	University of North Carolina, Chapel Hill. Invitation for a symposium.
April 1982	Invitation to be instructor of the image processing course of the European Molecular Biology Organization in Heidelberg, W. Germany.
June 6, 1982	Lecture at the Roche Institute of Molecular Biology, Nutley, NJ.

August 1982	Lecture at the Tenth International Congress on Electron Microscopy in Hamburg, W. Germany.
September 23, 1982	Department of Biochemistry, Columbia University: "Molecular Structure Research Using Electron Microscopy and Multivariate Image Analysis."
October 7, 1982	Lecture at the Brookhaven National Laboratory, Biology Department.
October 24-25, 1982	Symposium organized by the Duke University Marine Biology Laboratory.
March 24-25, 1983	Workshop on Image Processing in Electron Microscopy, Pennsylvania Muscle Institute: "Averaging and Classification of Molecule Images."
August 6-12, 1983	EMSA Symposium. "The Role of Multivariate Image Analysis in Solving the Architecture of the Limulus Polyphemus Hemocyanin Molecule."
October 22, 1983	College of St. Rose, Albany. Lecture in the series on Science and Public Issues.
October 26, 1983	Lecture at the Department of Anatomy, Howard University, Washington, DC.
Nov. 23-Dec. 3, 1983	American Society for Cell Biology, Workshop on Frontiers in Electron Microscopical Techniques: "Molecular Structure Research Using Electron Microscopy and Image Processing."
December 8, 1983	Advisory Committee (together with Drs. Palade and Sabatini) to evaluate research activities at Duke University Anatomy Department funded by a gift from Reynolds Company.
March 2, 1984	Lecture at the Department of Biophysics, University of Chicago.
April 2-3, 1984	NIH site visit committee for renewal of HVEM Biotechnology Resource grant in Madison, WI.
July 2-6, 1984	Invitation to speak at the Gordon Conference on Diffraction Methods in Molecular Biology.
July 16-18, 1984	NIH study section to review Professor L. Peachey's application for "Mid-Atlantic Regional Intermediate Voltage Electron Microscope and Image Analysis Resource."
July 27, 1984	Lecture at the Medical Research Council in Cambridge, England.
July 29-Aug. 4, 1984	8th International Biophysics Congress. Invitation to give a lecture at the symposium on image reconstruction.
August 13-18, 1984	8th European Congress on Electron Microscopy Symposium presentation entitled: "Recent Advances of Image Processing in the Structural Analysis of Biological Macromolecules."
December 1984	Invitation to contribute to a workshop on the use of supercomputers in scientific research organized by NSF.
July 8-12, 1985	Discussion leader of Gordon Conference on Three-Dimensional Electron Microscopy of Macromolecules.
February 25, 1986	Lecture on 3-D reconstruction of macromolecules at Wayne State University, Detroit, MI.
March 18-21, 1986	Conference of the New York Academy of Sciences: "Recent Advances in Electron and Light Optical Imaging in Biology and Medicine."
August 2, 1986	Symposium on Membrane Biochemistry and Bioenergetics, Rensselaerville, NY: "New Advances in Electron Microscopy of Biomolecular Assemblies."
August 10-15, 1986	Workshop on 3-D reconstruction of thick sections in EM at the meeting of the Electron Microscopy Society of America in Albuquerque, New Mexico. Invited lecture.
Aug. 31-Sept. 7, 1986	XI International Congress on Electron Microscopy in Kyoto, Japan. Lecture in session on "Tomographic Techniques in Electron Microscopy."
October 31, 1986	Physics Department, SUNY. "Study of Large Macromolecular Assemblies by High Resolution EM and Image Reconstruction",
November 5-7, 1986	Conference for Scientific Computing and Automation, Atlantic City. Lecture on 3-D electron tomography.
March 13, 1987	University of Michigan, Ann Arbor. Lecture on 3-D electron tomographic reconstruction.
March 16, 1987	Session on Microtomography in Electron Microscopy. Conference of the American Physical Society, New York City. Invited lecture.
September 13, 1987	MRC LMB, Cambridge, UK. Workshop on Multivariate Statistical Image Analysis.

Invited lecture.

March 11, 1988	Conference on 3-D Image Processing in Microscopy in Giessen, W. Germany. "Refinement of 3-D Reconstructions Using MSA, Classification, and Trial Projections,"
April 11, 1988	Physics Department, SUNY Albany. "Electron Microscopy and Image Reconstruction,"
April 29, 1988	Fourth Sitges Conference on Protein-Nucleic Acid Interactions. "The Architecture of Ribosomes as Revealed by Electron Microscopy and Non-crystallographic Image Processing."
September 22, 1988	Meeting of the Irish Biochemical Society in Galway, Ireland. Invited lecture: "EM Structure Determination of Aperiodic Macromolecular Assemblies."
October 14, 1988	Vanderbilt University. "3D Structure of Macromolecular Assemblies Studied by EM."
March 6, 1989	Center for Biochemistry and Biophysics, SUNY Albany: "The Structure of Ribosomes."
July 22-24, 1990	NIH Special site visit for review of Dr. L. Peachey's RR proposal, Philadelphia, PA.
August 16, 1990	Chairman of Symposium on Novel Methods of Analysis in 2D and 3D Microscopy at the XII Intl. Congress on Electron Microscopy in Seattle, WA.
October 23, 1990	NIH PB Study Section, special review assignment.
April 11, 1991	Scanning '91 meeting in Atlantic City, New Jersey: "3D Reconstruction of Macromolecular Assemblies Embedded in Ice."
April 18-20, 1991	Ad-hoc Member of Scientific Advisory Committee of European Molecular Biology Lab in Heidelberg. Meeting to review Program in Structural Biology.
June 10-12, 1991	Special Site visit to review P01 NIH proposal by Hauptmann et al., Buffalo, NY.
July 1-5, 1991	Chairman of Gordon Conference on 3D Electron Microscopy of Macromolecules.
August 6-8, 1991	Lecture at the Electron Microscopy Society Meeting, San Jose, CA, entitled: "New Challenges to Image Processing Posed by Cryo-EM of Single Macromolecules."
August 26-27, 1991	Ad-hoc panel to advise Division of Computer Research and Technology (DCRT), NIH on Image Technologies Program.
September 16-19, 1991	Tenth Pfeifferkorn Meeting on Image and Signal Processing, Cambridge, England: "Alignment, Classification, and 3D Reconstruction of Single Particles Embedded in Ice."
November 15, 1991	Advisory board of W.M. Keck Center for Computational Biology. Rice University and Baylor College of Medicine, Houston, TX.
December 2-7, 1991	Schloss Ringberg (W. Germany) meeting on Quantitative Electron Microscopy: "3D Reconstruction of Single Biological Particles Negatively Stained or Embedded in Ice."
February 5-8, 1992	BBCB Study Section: Special review of grants.
February 28, 1992	University of Alabama. Mini-symposium on Structural Biology: "Reconstruction of the Ribosome Using Cryo-Electron Microscopy."
May 7, 1992	Duke University Medical Center: "The Structure of the <i>E. coli</i> Ribosome."
August 16-21, 1992	50th Annual Meeting of the Electron Microscopy Society of America. Two invited lectures: (1) "Density-Based Discrimination of Protein and RNA in the Ribosome;" (2) "Electron Tomography's Remaining Problems: How to Fill the Wedge in Fourier Space and How to See What You've Got in Real Space."
September 7-11, 1992	10th European Congress on Electron Microscopy. Session chairman and two invited lectures: (1) "Three-Dimensional Cryo-Imaging of Macromolecular Assemblies Using the Random-Conical Data Collection Method.;" (2) "Classification and 3D Variance Estimation: Complementary Tools in the 3D Reconstruction of Macromolecules."
February 15, 1993	Award lecture on the occasion of receiving the Elizabeth Roberts Cole Award of the Biophysical Society (with David DeRosier), Washington, DC. "Electron Crystallography Without Crystals".
March 15-16, 1993	NSF Workshop to determine directions of Computational Biology Program, Washington, DC.
March 18, 1993	University of Pennsylvania, Philadelphia: "Electron Crystallography Without

	Crystals.”
May 11, 1993	Max-Planck-Institut for Medical Research, Heidelberg: “Electron Crystallography Without Crystals.”
August 1-6, 1993	51st Annual Meeting of the Electron Microscopy Society of America, Cincinnati, Ohio. Lecture on Electron Tomography.
May 23-27, 1994	American Society for Microbiology Meeting in Las Vegas, Nevada: “The Structure of the Bacterial Ribosome Explored by 3D Electron Microscopy.”
July 17-22, 1994	13th International Congress for Electron Microscopy in Paris, France: “The Role of Electron Microscopy in Visualizing Biological Complexity.”
May 21-24, 1995	International Conference on Translation, Victoria, B.C., Canada: “Model of Protein Synthesis Based on a New Cryo-EM Reconstruction of the <i>E. coli</i> Ribosome.”
July 17-21, 1995	Conference of the English Biochemical Society, Manchester: “Crystallography Without Crystals.”
January 17, 1996	Department of Biochemistry and Molecular Genetics, University of Alabama at Birmingham: “Functional Binding Studies of the <i>E. coli</i> Ribosome.”
April 25, 1996	Vienna Biocenter Seminar Programme, Vienna: “Protein Synthesis in Three Dimensions.”
April 26, 1996	Fifth Max Gruber Lecture at the University of Groningen, The Netherlands: “Protein Synthesis in Three Dimensions.”
April 29, 1996	European Molecular Biology Laboratory in Heidelberg: “The Ribosome: Initiation and Elongation.”
May 18-22, 1996	Presenter and co-organizer at 15 th Pefferkorn Conference on Signal Processing, Silber Bay, NY. Lecture entitled: “Three-Dimensional Reconstruction from Low-Dose Electron Micrographs of Biological Particles-Maturation and Convergence of Techniques.”
June 2-6, 1996	American Society for Biochemistry and Molecular Biology Meeting, New Orleans, LA: “Visualization of the Translational Apparatus.”
August 3-7, 1996	Tenth Symposium of the Protein Society, San Jose, CA: “Protein Synthesis in Three Dimensions.”
September 1-6, 1996	Gordon Conference for Macromolecular Organization and Cell Function, Oxford, England: “The Cryo-EM Reconstruction of the <i>E. coli</i> Ribosome--A Framework for Functional Studies.”
December 8, 1996	Cell Biology Conference, Symposium on High Resolution Microscopy of Membrane Proteins and Other Macromolecules: “Imaging of Functional States of the Ribosome.”
December 9, 1996	Seminar at UC Riverside, Department of Biochemistry: “Imaging of Functional States of the Ribosome.”
January 10-11, 1997	Invited participant at Symposium given in honor of Dr. Don Caspar, Florida State University, Tallahassee. Symposium title: “Motion and Adaptability in Living Molecules.”
March 16-19, 1997	Workshop on Electron Tomography, Ringberg Castle, Rottach-Egern, Germany: “Tinkerbelle – Development of Interactive Interpretation Software for Tomography.”
March 21, 1997	Novum, Karolinska Institute, Stockholm: “Cryo-EM of the Ribosome in its Functional States.”
March 27, 1997	Seminar at Department of Chemistry and Biochemistry of the University of Delaware: “Translation in Three Dimensions – What we Learn from Cryo-Electron Microscopy of the Ribosome.”
May 3, 1997	Symposium of the Center for Structural Biology, SUNY Buffalo. “Cryo-EM of ribosomes”.
May 6, 1997	Seminar at National Institute of Health (Dr. A. Steven’s group): “Cryo-EM of ribosomes.”
September 17-20, 1997	Conference on Structural Aspects of Protein Synthesis in Tällberg, Sweden: “Binding States of the Ribosome During Protein Synthesis as Explored by Cryo-Electron

Microscopy.”

- May 17-21, 1998 Meeting of the American Society for Microbiology in Atlanta, Georgia: “Structure and Binding States of the *E. coli* Ribosome.”
- May 27, 1998 Lecture at Symposium on “Imaging in the Cell,” at Rockefeller University, NY.
- July 13, 1998 Meeting of the Microscopy Society of America in Atlanta, GA: “The Ribosome – 3D Structure and Ligand Binding Studies.”
- September 9-10, 1998 Howard Hughes Medical Institute's New Technology in Cell Biology and Genomics Workshop in Bethesda, MD: “Cryo-electron Microscopy of Macromolecular Assemblies.”
- September 25-27, 1998 Retreat of the Sackler Institute, NYU: “Structure and Function of the Ribosome as Explored by Cryo-Electron Microscopy.”
- October 6, 1998 Michigan State University in East Lansing, MI: “Structure and Function of the Ribosome as Explored by Three-Dimensional Cryo-Electron Microscopy.”
- October 14, 1998 University of Illinois at Urbana, IL: “Structure and Function of the Ribosome as Explored by Three-Dimensional Cryo-Electron Microscopy.”
- October 23, 1998 Mount Sinai School of Medicine in NYC: “The Ribosome – Structure and Functional Binding Studies Using Cryo-Electron Microscopy.”
- December 6-9, 1998 International Meeting of the Molecular Graphics and Modeling Society at Scripps Research Institute in San Diego, CA: “The Ribosome – An Astounding Molecular Machine.”
- December 9-12, 1998 Workshop on Electron Crystallography of Biological Macromolecules in Lake Tahoe, CA: “The Elongation Cycle of the Translating Ribosome – A Four-Dimensional Jigsaw Puzzle.”
- February 23, 1999 Kyoto University in Kyoto, Japan: “Structure of Ribosome Visualized Directly with Cryo-Electron Microscopy.”
- February 24-25, 1999 JST International Symposium in Tokyo, Japan: “Structure and Functional Binding Studies Using Cryo-Electron Microscopy.”
- February 26, 1999 Academia Sinica, Nankang, Taipei Taiwan: “The Ribosome – Structure and Functional Binding Studies Using Cryo-Electron Microscopy.”
- March 19-22, 1999 ABRF '99 Symposium in Durham, NC: “Structure and Function of the Ribosome as Explored by Three-Dimensional Cryo-Electron Microscopy.”
- April 14-17, 1999 Seminar at the University of Arizona, in Tuscon, AZ: “Ribosome Structure and Functional Ligand Binding Visualized in Three Dimensions by Cryo-Electron Microscopy.”
- May 4-7, 1999 Lecture at BioImage General Meeting in Grenoble, France.
- June 13-17, 1999 Ribosome Conference in Helsingoer, Denmark: “Initiation and Elongation Steps of Protein Synthesis Elucidated by Cryo-Electron Microscopy.”
- September 19-22, 1999 Protein Society Symposium in Garmisch-Partenkirchen, Germany: “Cryo-Electron Microscopy: Study of Macromolecular Interactions and Applications to the Ribosome.”
- October 20-21, 1999 Served as a member of Life Sciences Review Committee at the Lawrence Berkeley National Laboratory in Berkeley, CA.
- November 3-6, 1999 Symposium on Structure and Mechanisms of Membrane Channels in Hyogo, Japan: “Interaction of the Ribosome with Key Ligands during Protein Synthesis as Elucidated by Cryo-Electron Microscopy.”
- November 22, 1999 Seminar at Utica College, in Utica, NY: “Interaction of the Ribosome with Key Ligands During Protein Synthesis as Elucidated by Cryo-Electron Microscopy.”
- November 29, 1999 Seminar at Purdue University in Indiana: “The Structure of the Ribosome and the Mechanism of Protein Synthesis as Explored by Cryo-Electron Microscopy.”
- December 2, 1999 Seminar at Weill Medical College of Cornell University in New York City, NY: “Ribosome Structure and Function Explored by Cryo-Electron Microscopy.”
- December 11-15, 1999 American Society for Cell Biology Meeting in Washington, DC: “The Ribosome – Structure and Dynamical Interaction with Ligands Explored by Cryo-Electron Microscopy.”
- March 26-29, 2000 European Molecular Biology Laboratory, Symposium in Structural Biology, in

Heidelberg, Germany: “The Ribosome – Evidence for Conformational Switching Obtained by Cryo-Electron Microscopy.”

May 19-21, 2000 Lecture at the Sealy Center for Structural Biology Symposium in Galveston, TX.

June 25-30, 2000 Chaired a session on Macromolecular Assemblies at the Nucleic Acids Gordon Conference at the University in Newport, RI, and presented a lecture.

July 16-20, 2000 IUBMB/FEBS 2000 Congress in Birmingham, UK: “The Ribosome – Structure and Functional Binding Studies using Cryo-Electron Microscopy.”

October 18, 2000 Seminar at University of Toronto, Canada: “The Ribosome – A Molecular Machine in Motion: Evidence from Cryo-Electron Microscopy.”

November 12-15, 2000 HHMI Scientific Meeting in Chevy Chase, MD: “Macromolecules and Molecular Machines.”

January 8, 2001 Lecture at the bimonthly Structural Biology Meeting at Rockefeller University.

January 12-13, 2001 Seminar organized by NIGMS at the American Mathematical Society in New Orleans, LA: “Three-Dimensional Cryo-Electron Microscopy of Biological Macromolecules: The Challenge Posed by Structural Heterogeneity.”

February 14, 2001 Seminar at Brandeis University in Waltham, MA: “The Ribosome: A Molecular Machine in Motion.”

March 4-8, 2001 Second International Conference on “Proteins That Bind RNA” in Austin/Lake Travis, TX: “Ribosome Structure and Functional Dynamics.”

March 14, 2001 Lecture at the University of Pennsylvania.

March 25-28, 2001 HHMI Scientific Meeting in Chevy Chase, MD: “The Ribosome as a Battlefield: Structural Aspects of Antibiotics Resistance and IRES.”

March 31-April 4, 2001 American Society for Biochemistry and Molecular Biophysics in Orlando, FL: “The Dynamics of the Ribosome During Elongation as Explored by Cryo-Electron Microscopy.”

April 11, 2001 Seminar at Cornell University in Ithaca, NY: “The Ribosome: A Macro-molecular Machine in Motion – Evidence from Cryo-Electron Microscopy.”

April 23-27, 2001 Lectures at Uppsala University and Karolinska Institute in Sweden: “Ribosome Structures and Hepatitis C Virus IRES RNA-Induced Changes.”

May 9, 2001 Wesleyan University in CT: “The Ribosome – A Molecular Machine in Motion as Seen by Cryo-Electron Microscopy.”

May 17-19, 2001 Workshop on New Approaches to the Phase Problem for Non-Periodic Objects at Lawrence Berkeley Laboratory, Berkeley, CA: “Cryo-Electron Microscopy and 3D Reconstruction of Single Asymmetric Biological Molecules.”

May 31-June 4, 2001 Ribosome Meeting at Cold Spring Harbor: “Cryo-Electron Microscopy Provides Snapshots of the Ribosome in Motion.”

June 19-20, 2001 Albany 12th Conversation meeting at SUNY at Albany, NY: “Multiple Conformational States of the Ribosome.”

June 24-29, 2001 Gordon Conference on Three-Dimensional EM: “Multiple Conformational States of the Ribosome.”

August 28, 2001 Lecture at the 22nd ACS Meeting in Chicago, IL.

September 5, 2001 City College of CUNY: “Cryo-EM, Single-Particle Reconstruction: The Study of Molecular Machines.”

September 15, 2001 Albany Conference on Biotechnology at Rensselaerville, Albany, NY: “The Ribosome – A Molecular Machine in Motion.”

October 10, 2001 Seminar at University of Chicago entitled: “The Ribosome as a Battleground: Drug Resistance and Viral Hijacking Studied by Cryo-EM.”

October 11, 2001 Weill Medical College in NY: “The Ribosome: Snapshots of a Molecular Machine in Motion.”

October 17-20, 2001 Served on the Program Committee for the Second International Electron Tomography Workshop in Amsterdam, The Netherlands. Lecture entitled: “Three-Dimensional Imaging of Biological Complexity.”

November 2-4, 2001 Structure and Function of Biomacromolecules Workshop in Sitges, Spain: “The Ribosome, a Molecular Machine in Motion: Evidence from Cryo-EM.”

January 10, 2002 Graduate Student lecture at Scripps Research Inst. in CA: “Single Particle Methods,” and a general seminar: “The ribosome: Snapshots of a Machine in Motion.”

Jan. 27-Feb.1, 2002 Meeting on Dynamics of Ribosome Structure and Function in Queenstown, New Zealand: “Functional Dynamics of the Ribosome Inferred by Cryo-Electron Microscopy.”

February 23-27, 2002 Biophysical Society Meeting in San Francisco, CA: “Toward a Molecular Understanding of the Ratchet Movement.”

April 2-4, 2002 Seminar at the Agouron Institute’s Second Structural Biology Meeting in Scottsdale, AZ: “The Ribosome – Dynamics of a Macromolecular Machine,” and “SPIDER – New Developments.”

April 16, 2002 Lecture at the Mt. Sinai School of Medicine in NY.

April 19-22, 2002 Seminar at the Biophysical Discussions Workshop in Asilomar, CA: “The Ribosome – A Molecular Machine in Motion.”

May 21-23, 2002 Seminar at the American Society for Microbiology meeting in Salt Lake City, UT: “The Ribosome – A Molecular Machine in Motion as Studied by Cryo-EM.”

June 16-17, 2002 Biopolymers Gordon Conference in Newport, RI: “The Ribosome – A Molecular Machine in Motion as Seen by Cryo-EM.”

August 5-8, 2002 Co-chaired the MSA 2002 Meeting in Quebec, Canada.

August 26-30, 2002 Nobel Symposium in Stockholm, Sweden: “The Dynamics of the Ribosome as Inferred by Cryo-EM: Induced and Self-Organized Motions.”

September 1-6, 2002 Plenary Lecture at the ICEM Meeting in Durban, South Africa: “Cryo-Electron Microscopy of the Ribosome and the Elucidation of the Mechanism of Translation.”
Symposium lecture: “Toward High Resolution (<10Å) in Cryo-EM Reconstruction of Asymmetric Single Particles.”

September 16-17, 2002 Seminar at the University of Sherbrooke, Canada: “The Dynamics of Ribosome-Ligand Interaction as Explored by Cryo-EM.”

September 17-18, 2002 Seminar at McGill University in Montreal, Canada: “Ribosomal Structure and Dynamics Explored by Cryo-Electron Microscopy.”

September 22-25, 2002 HHMI Scientific Meeting in Bethesda, MD: “What Makes it Tick? Studies of Ribosome Dynamics using Cryo-EM.”

October 14, 2002 Bio-informatics Seminar at the University of Chicago, Chicago, IL: “The Dynamics of the Ribosome as Inferred by Cryo-EM: Induced and Self-Organized Motions.”

November 11, 2002 Seminar at Rensselaer Polytechnic Institute in Troy, NY: “The Dynamics of the Ribosome as Inferred by Cryo-EM: Induced and Self-Organized Motions.”

December 10, 2002 Stony Brook University, NY: “The Dynamics of the Ribosome as Inferred by Cryo-EM.”

February 11, 2003 Panel of the U.S. Department of Energy Genomes to Life Program Workshop in Washington, DC: “Visualization of Macromolecular Interactions by Cryo-EM.”

February 13, 2003 Seminar at CUNY Graduate Center in New York: “Structure and Dynamics of the Ribosome by 3D Cryo-Electron Microscopy – A Computational Challenge.”

February 28, 2003 Seminar at SUNY Albany: “The Functional Dynamics of the Ribosome as Explored by Cryo-EM.”

March 13, 2003 Seminar at Stanford University, CA: “The Ribosome: Dynamics of Structure and Ligand Interactions as Inferred by Cryo-Electron Microscopy.”

March 26-29, 2003 Keystone Symposia on Proteomics, Technologies and Applications, in Keystone, CO: “Single-Particle Reconstruction of Molecular Machines using Cryo-Electron Microscopy.”

April 14, 2003 Seminar at Wayne State University in Detroit, MI: “What Makes it Tick – Attempts to Understand the Dynamics of the Ribosome Using Cryo-EM.”

April 24-27, 2003 Invited participant of the “DNA: 50 Years of the Double Helix” Meeting of LMB/MRC in Cambridge, UK.

May 7, 2003 Future of Structural Biology Conference at the NY Structural Biology Center in New York City: “What Makes it Tick – Attempts to Understand the Dynamics of the Ribosome Using cryo-EM”.

May 14, 2003 Seminar at NIH Director’s Wednesday Afternoon Series in Bethesda, MD: “What Makes it Tick – Attempts to Understand the Dynamics of the Ribosome Using Cryo-EM.”

May 21-22, 2003 Brookhaven National Laboratory in Upton, NY: “Toward an Understanding of Protein Synthesis as a Dynamic Process: Cryo-Electron Microscopy and Molecular Dynamics

June 9, 2003
 August 3-7, 2003
 August 15, 2003
 Aug. 26-Sept. 2, 2003
 Sept. 29-Oct. 3, 2003
 October 12-15, 2003
 October 27 & 29, 2003
 October 30-31, 2003
 November 11-17, 2003
 November 24-27, 2003
 February 11, 2004
 Feb. 29-Mar 3, 2004
 March 17-20, 2004
 March 29, 2004
 May 6, 2004
 May 23-27, 2004
 June 6-11, 2004
 June 28, 2004
 July 9-15, 2004
 September 22-23, 2004
 October 10-15, 2004
 October 23-24, 2004
 November 30, 2004
 December 6, 2004
 December 7, 2004
 February 6-10, 2005
 February 12-16, 2005
 April 28, 2005
 May 19-20, 2005

Simulations of the Ribosome.”
 Lecture at Nature Structural Biology Discussion Meeting in New York City.
 2003 Distinguished Scientist Award for the Biological Sciences at the Microscopy Society of America’s 61st Annual Meeting in San Antonio, TX.
 Lecture at the University of Vermont, Dept. of Molecular Physiology and Biophysics.
 Conference on Structure and Function of Non-Coding RNA in Sandhamn, Sweden: “Ribosomal Dynamics as Inferred by Cryo-Electron Microscopy.”
 Aarhus University, Dept. of Molecular Biology in Sweden: “Translational Dynamics Inferred from Cryo-EM of Functional Ribosome Complexes.”
 HHMI Gene Regulation and Genome Organization Meeting: “A Dynamic Interplay Between the Ribosome and tRNA, as Seen by Cryo-EM.”
 Lecture at Columbia University for the Biochemistry & Molecular Biology of Eukaryotes I & II Graduate course.
 Participated in a multiple grant review at NIH in Bethesda, MD.
 Participated in the Molecular Microscopy Workshop at Scripps Research Institute, La Jolla, CA.
 RNA meeting in Kyoto, Japan: “Functional Dynamics of the Ribosome as Inferred by Cryo-Electron Microscopy.”
 Seminar at Tufts University in Boston, MA: “Ribosomal Dynamics as Inferred by Cryo-Electron Microscopy.”
 HHMI Science Meeting in Bethesda, MD: “Interaction of the Signal Recognition Particle (SRP) with the Elongation-Arrested 80S Ribosome.”
 Lecture at the International Hybrid Structural Biology Conference in Lake Tahoe, CA.
 Seminar at Johns Hopkins University: “The Dynamics of Decoding and Accommodation as Seen by Cryo-EM.”
 Seminar at SUNY Downstate Medical Center: “The Ribosome: Glimpses of a Molecular Machine in Motion.”
 American Society for Microbiology Meeting in New Orleans, LA: “The Functional Dynamics of the Ribosome as Explored by Cryo-EM.”
 Lecture at the 2004 Nucleic Acids Gordon Conference.
 Symposium in Honor of Dr. Peter Ottensmeyer in Toronto, Canada: “The Ribosome – Glimpses of a Molecular Machine in Motion.”
 Panelist at Joint Workshop with Max-Planck and HHMI – Frontiers of Molecular Imaging, Max-Planck, Munich, Germany.
 National Institute of Environmental Health Sciences in Research Triangle Park, NC: “The Ribosome – A Molecular Machine in Motion.”
 Nobel Symposium on Molecular Mechanisms of Biological Processes, Tällberg, Sweden: “The Process of Decoding and Accommodation – Insights from Cryo-EM snapshots.”
 Participated in the Cryo-EM Workshop at Rutgers University.
 MRS Meeting on Electron Microscopy of Molecular and Atom-Scale Mechanical Behavior, Chemistry, and Structure in Boston, MA: “Observing the Dynamics of Molecular Machines by 3D Cryo-EM & Potential and Limitations as Exemplified by the Ribosome.”
 Lecture at Harvard University, Biochemistry graduate class: “The Ribosome – A Molecular Machine in Motion.”
 Participated in NIH Review.
 Annual Lorne Conference on Protein Structure and Function, Australia: “Cryo-Electron Microscopy of the Ribosome – Glimpses of a Molecular Machine in Motion.”
 National Lecturer of the Biophysical Society 2005 Annual Meeting in Long Beach, CA: “Cryo-Electron Microscopy of the Ribosome: Glimpses of Molecular Machine in Motion.”
 Biochemistry Department Seminar Series at Univ. Texas Southwestern Medical Center in Dallas, TX: “The Dynamics of the Decoding Process Inferred by Cryo-EM of Ribosomal Complexes.”
 Molecular Imaging and Characterization Meeting at the University of Montreal,

May 24-29, 2005	Canada: “Molecular Machines by Cryo-TEM: The Ribosome as an Example.” Tenth Annual Meeting of the RNA Society: “Dynamics of Decoding Inferred by Cryo-Electron Microscopy.”
June 2-3, 2005	Lecture at the Meeting on Structural Analysis of Large Macromolecular Assemblies: Sizing up the Challenges at NIH.
June 15, 2005	Chaired a session at the Albany 2005: Conversation 14 Conference at SUNY Albany.
July 8-10, 2005	Workshop on Mechanism and Control of Posttranscriptional Gene Expression at the New York Academy of Sciences, NY: “Structural aspects of protein synthesis in prokaryotes and eukaryotes.”
July 23-28, 2005	Meeting on Microbes in a Changing World, in San Francisco, CA: “Structure of the 80S Ribosome from <i>Trypanosoma cruzi</i> : Novel rRNA Components Associated with Translation Initiation.”
August 23-28, 2005	20th Congress of the International Union of Crystallography in Florence, Italy: “Cryo-Electron Microscopy of the Ribosome: Methods of Fitting, and Inference of Dynamics.”
Aug. 28-Sept.2, 2005	Plenary Lecture at the Microscopy Conference Davos 2005 in Davos, Switzerland: “Three-Dimensional Cryo-EM of the Ribosome: What Can We Learn about the Dynamics of Translation?”
Sept. 12, 2005	Invited participant at Workshop on Multi-Teraflop Computing in Biology, Materials and Energy Science, at Brookhaven National Laboratory in Long Island, NY.
Sept. 27, 2005	Seminar at the Hauptman-Woodward Medical Research Institute in Buffalo, NY: “The dynamics of translation as inferred from cryo-electron microscopy of ribosomal complexes.”
Nov. 2-10, 2005	Contributed to the NRAMM Cryo-EM Workshop at The Scripps Research Institute in La Jolla, CA.
Jan. 29-Feb. 3, 2006	Keystone Symposia, Frontiers in Structural Biology and Structural Genomics, Keystone Resort, Keystone CO: “Application of Cryo-EM to Image Ribosome Dynamics”
Feb. 13-14, 2006	Seminar at the Georgia Institute of Technology: “The ribosome – structure and dynamics as seen by cryo-electron microscopy.”
Feb 15, 2006	Seminar at Rensselaer Polytechnic Institute: “The Ribosome as a Molecular Machine, as seen by Cryo-EM.”
Feb 20-22, 2006	NIH Site visit, University of Dallas, Texas.
Feb. 27-28, 2006	Seminar at the Beckman Institute at the University of Illinois: “The dynamics of translation as seen by cryo-electron microscopy.”
April 3-6, 2006	American Society for Biochemistry and Molecular Biology Annual Meeting: “Cryo-EM studies of the translocation process.”
April 27-28, 2006	seminar at the Theoretical and Physics Division at Los Alamos National Laboratory, New Mexico: “The Ribosome as a Molecular Machine, as Seen by Cryo-EM.”
May 11-14, 2006	Annual Basel Imaging Symposium: Frontiers in Bioimaging in Basel, Switzerland: “The dynamics of the translation process.”
June 8-18, 2006	Meeting on Structure and Function of Large Molecular Assemblies in Erice, Italy: “Atomic models of the ribosome in different functional states, by cryo-EM and real-space refinement.”
June 25-30, 2006	Chair for the Reconstruction Methods and Heterogeneity Session at the 3DEM Gordon Conference in Barga, Italy.
July 16-20, 2006	Thirty Years of Analytical EM Meeting at Cornell University: “The Future of cryo-EM.”
Aug. 5-9, 2006	Chair and Speaker at the Macromolecular Machine session at the 20 th Symposium of the Protein Society, San Diego, CA: “Functional dynamics of the ribosome as inferred by Cryo-EM.”
Sept. 6-10, 2006	Cold Spring Harbor meeting on Translational Control, Cold Spring Harbor, NY: “The Mechanism of mRNA-tRNA Translocation as Revealed by Cryo-electron Microscopy of Eubacterial and Eukaryotic Ribosome Complexes.”
Oct. 24-28, 2006	First African Structural Biology Conference, Capetown, South Africa: “The Ribosome in Motion as Seen by cryo-EM.”

Dec. 3-6, 2006 HHMI Scientific Meeting, Janelia Farms, Virginia NY: “The Mechanism of mRNA-tRNA Translocation, as Inferred by Cryo-EM of EF2-80S Complexes.

January 29, 2007 Seminar at New York University School of Medicine: ”Seeing Protein Synthesis in Motion: Results from Visualizing Ribosomes Performing Work by Cryo-electron Microscopy.”

Feb. 11-14, 2007 HHMI Scientific Meeting, Chevy Chase, MD: “RNA as Conduct of Conformational Signaling of the Ribosome.”

June 3-8, 2007 Ribosomes 2007 Meeting, Cape Cod, MA: “Ratchet Motion as a Universal Mechanism: Conformational Signaling in the Ribosome during Translocation and Termination.”

March 25-29, 2007 American Chemical Society 233rd National Meeting, Chicago, IL: “Cryo-EM Results on mRNA-tRNA Translocation in the 80S Ribosome.”

April 28-May 1, 2007 Inaugural Section talk, National Academy of Sciences 2007 Annual Meeting, Washington, DC: “Watching a Ribosome Do Its Work -- What We Learned From Cryo-EM.”

June 19-23, 2007 15th Conversation on Structural Dynamics in Albany, NY: “The Mechanism of mRNA-tRNA Translocation as Inferred from Cryo-EM of 80S-EF2 and 70S-EF-G complexes.

July 11-13, 2007 Site-visit Review panel of the MacCHESS Research Resource at Cornell, Center for Scientific Review Special Emphasis Panel, Cornell University, Ithaca, NY.

August 8-9, 2007 NIH Mid-course Review of the Technology Centers for Networks and Pathways Program, Arlington, VA.

September 26, 2007 Seminar at University of Guelph, Toronto, Canada: “Protein Synthesis and the Dynamic Workings of the Ribosome Explored by Cryo-EM.”

September 28, 2007 Computational Biology/Bioenergy Workshop and Mini-Symposium, Brookhaven National Laboratory: “Computational Challenges in Pushing Cryo-EM of the Ribosome toward Atomic Resolution.”

October 8, 2007 University of Arizona, Eminent Scholar Series Seminar, Tucson, AZ: “The Mechanism of mRNA-tRNA Translocation as Inferred by Cryo-EM.”

October 13, 2007 University of Connecticut Partnership for Excellence in Structural Biology, 4th North Eastern Structure Symposium, Storrs, CT: “Insight into the Mechanism of mRNA-tRNA Translocation.”

October 24-26, 2007 Motion Bio-X Symposium, Stanford University, CA: “The Ribosome in Motion, as seen by Cryo-EM.”

November 1-6, 2007 22nd tRNA Workshop, Uppsala, Sweden: “Structural insights into the Decoding Mechanism using the Hirsch Suppressor tRNA.”

November 10-26, 2007 NRAMM Workshop on Advanced Topics in EM Structure Determination, The Scripps Research Institute, La Jolla, CA: “Conformational Variability - Experience with Ribosomes.”

December 5 - 7, 2007 University of Missouri-Kansas City, UMKC School of Biological Sciences, Trailblazer Lecture Series: “The Mechanism of mRNA-tRNA Translocation as Inferred by Cryo-EM.”

December 12-14, 2007 Advisory Committee Meeting for MMTSB, La Jolla, CA.

January 28-February 1, 2008 University of California, Image Analysis Challenges in Molecular Microscopy: “Single-particle Reconstruction of the Ribosome -- The Struggle to Get Toward Atomic Resolution.”

February 2-6, 2008 Joint Biophysical Society 52nd Annual Meeting, 16th International Biophysics Congress, Long Beach California: “The A/T (Pre-accommodated) State Observed with the Phe-tRNA.”

March 12-16, 2008 Fourth International Symposium, Structural Analysis of Supramolecular Assemblies by

Hybrid Methods, Lake Tahoe, CA: “Demonstration of Different Approaches to Flexible Fitting of Ribosome Maps.”

March 17-30, 2008 Okazaki Institute for Integrative Bioscience, National Institutes of Natural Sciences: “The Dynamics of the Ribosome During Translation as Inferred by Cryo-EM.” -- Department of Biophysics, Faculty of Science, Kyoto University: “The Mechanism of mRNA-tRNA Translocation as Inferred by Cryo-EM.”

May 5-6, 2008 Seminar at Harvard Medical School, Boston, MA: “Structure Determination Using Single-Particle Reconstruction.”

June 23-25, 2008 CNIO Cancer Conference, on Structure and Mechanisms of Essential Complexes for Cell Survival, Madrid, Spain: “The Mechanism of Translation as Observed by Cryo-Electron Microscopy.”

August 6, 2008 NYSBC meeting, Cold Spring Harbor Laboratory, NY: “The Ribosome: a Molecular Machine with Intrinsic Instability.”

August 27, 2008 Invitation to Address Harlem Children Society Lecture & Workshops Series.

September 3-7, 2008 Meeting on Translational Control, Cold Spring Harbor Laboratory, NY: “Visualization of the Hybrid State of tRNA Binding Promoted by Spontaneous Ratcheting of the Ribosome.”

September 23-24, 2008 Electron Microscopy Workshop, Janelia Farm Research Campus, Ashburn, VA.

October 22, 2008 Seminar at the Wayne State University, School of Medicine: “The Ribosome at Work- Snapshots of the Elongation Cycle Depict a Highly Dynamic Molecular Machine.”

November 12, 2008 Seminar at the Cornell University School of Applied and Engineering Physics entitled, “The Ribosome at Work.”

January 31-February 4, 2009 Keynote lecture, International Congress in Electron Tomography, Brisbane, Australia: “Electron Tomography Has Come of Age: from Molecules to Organelles to Cells to Tissues.”

March 29, 2009 EMD Scientific Advisory Committee Meeting, Houston, TX.

April 1-3, 2009 seminar at University of California at San Francisco: “Ribosomal Dynamics during Translation.”

April 19-21, 2009 Molecular Biophysics Seminar, University of Texas: “The Dynamics of the Ribosome as Seen by Cryo-EM.”

June 5-6, 2009 International CEF Symposium, Frankfurt, Germany: “The Decoding Process: Dynamics of tRNA Selection.”

June 16-20, 2009 RNA Session Chair at the 16th Conversation on Molecular Stereodynamics, SUNY, Albany NY.

July 7, 2009 NIH, Center for Scientific Review Special Emphasis Panel, Washington, DC.

September 9-13, 2009 Lecture at EMBO Conference on Protein Synthesis and Translational Control, EMBL Heidelberg, Germany.

October 2-3, 2009 Advanced Electron Microscopy in Nano-Medicine Symposium, UCLA: “Cryo-EM of the Ribosome -- The Workings of a Molecular Machine.”

October 18-21, 2009 HHMI Science Meeting, Chevy Chase, MD: “How tRNAs are Selected by the Programmed Ribosome.”

November 8-13, 2009 Lecture at Workshop on Advanced Topics in EM Structure Determination: Challenging Molecules, The Scripps Research Institute, San Diego, CA.

November 17, 2009 Seminar at Rutgers University: “The Ribosome -- Dynamics of a Molecular Machine Studied by Cryo-EM.”

December 14-15, 2009 Biotechnology Center, Meeting on Probing the Cell, Dresden, Germany: “Dynamics of the Ribosome During the Elongation Cycle as Visualized by Cryo-EM.”

May 3-7, 2010 Ribosomes 2010 Meeting, Rome, Italy: “Evidence for the Existence of Intermediate States During Translocation.”

May 18-20, 2010	Case Western Reserve University, School of Medicine, Cleveland, OH: "The Ribosome -- a Molecular Machine in Motion as seen by Cryo-EM."
September 8-12, 2010	University of Montana, Center for Biomolecular Structure and Dynamics: "Insights into the mRNA-tRNA Translocation Mechanism by Cryo-EM."
September 24-26, 2010	Lecture at Meeting on Structure & Function of the Ribosome, Sea Crest Resort, Falmouth, MA.
September 30, 2010	EMDB Advisory Committee Meeting, Rutgers University, Piscataway, NJ.
December 6-8, 2010	National University of Singapore, 6 th International Conference on Structural Biology and Functional Genomes: "Ribosome Structure and Dynamics Revealed by Cryo-EM: a Window into the Future."
April 1-2, 2011	Georgia Institute of Technology, 19 th Annual Suddath Symposium, The Ribosome Structure, Function and Evolution: "The Tedious Business of Going From A to B: Translocation Intermediates Visualized by Cryo-EM."
September 1-9, 2011	St. Petersburg Nuclear Physics Institute of the Russian Academy of Sciences, Molecular and Radiation Biophysics Division: "Dynamics of the Ribosome Explored by Cryo-Electron Microscopy."
October 3, 2011	EM Data Bank Advisory Committee Meeting, European Bioinformatics Institute, Hinxton, UK.
February 6-8, 2012	I2PC Developers Workshop, Madrid, Spain.
March 22-23, 2012	Seminar at the University of Michigan: "The Dynamics of Translation as Seen by Cryo-EM."
May 20-22, 2012	Lecture at SIAM Conference on Imaging Science, Philadelphia, PA.
May 13-20, 2012	University of Washington, Department of Biochemistry, School of Medicine: "The Mechanism of Protein Synthesis as Seen by Cryo-EM."
May 27-June 1, 2012	Gordon Research Conference, Les Diablerets, Switzerland: "Stories in a Sample -- the Potential of Cryo-EM Applied to Molecular Machines."
December 7-15, 2012	tRNA Conference, Lima, Peru: "Structural Insights of the Mammalian 43S Preinitiation Complex."
November 11-16, 2012	Contributions to NRAMM Workshop on Advanced Topics in EM Structure Determination, The Scripps Research Institute, La Jolla, CA.
October 18-19, 2012	Twenty Third Annual Distinguished Lecturer in Physiology and Biophysics, Virginia Commonwealth University: "The Ribosome as a Brownian Machine."
January 22-24, 2013	Lecture at Frontiers in Structural Physiology Symposium, Nagoya, Japan.
March 5-7, 2013	HHMI Science Meeting, Chevy Chase, MD: "The Eukaryotic Preinitiation Complex."
July 9-12, 2013	Ribosomes Conference, Napa Valley, CA: "Structural Insights into the Mammalian Ribosomal 43S Preinitiation Complex."
June 11-15, 2013	The 18 th Conversation on Molecular Stereodynamics at SUNY Albany: "High-Resolution Cryo-Electron Microscopy Structure of the <i>Trypanosoma brucei</i> Ribosome."
October 16-19, 2013	Solvay Conference in Chemistry, Brussels, Belgium: "How Proteins Are Made in The Cell: Visualizing The Ribosome in Action."
October 28-29, 2013	The Welch Foundation Conference, Houston, TX: "Cryo-Electron Microscopy of the Ribosome - Multiple States in a Single Sample."
March 16-20, 2014	Gene Center/SFB 646 Seminar Series, Munich, Germany: "Translation Initiation and Translocation as Seen by Cryo-EM."
April 21-25, 2014	2014 Franklin Institute Life Science Award, Philadelphia, PA.
June 22-27, 2014	Gordon Research Conference, Girona-Costa Brava, Spain: "Electron Microscopy and Ab Initio Modeling of Ribosomes -- A Dream Come True."

September 21-25, 2014	tRNA Conference, Kyllini, Greece: “Progression of tRNAs During Elongation.”
February 9, 2015	Seminar at Thomas Jefferson University, Dept. of Biochemistry and Mol. Biolog: “The enigma of mRNA-tRNA translocation, illuminated by new results from cryo-EM.”
May 4-6, 2015	Lecture at RiboCore Retreat, Uppsala, Sweden
June 20-21, 2015	Model Challenge Workshop, Cambridge, MA. Invited participant.
Dec 7-9, 2015	Conference on Multiscale Motility of Biomolecular Machines, Berlin Invited presentation: “Time-resolved cryo-EM of ribosomes during fast steps of translation”
Feb 26, 2016	Seminar at Hunter College, New York: “Cryo-EM Structures of Ribosomes Engaged in Translation – The Sky is the Limit”
March 17, 2016	Seminar at Dept. of Biological Sciences, University of Pittsburgh: “The <i>T. cruzi</i> ribosome at 2.5Å resolution, and how we got there.”
March 30 – April 1, 2016	Keynote lecture at Cryo-EM 3D Image Analysis Symposium, Granlibakken, Lake Tahoe.
May 9-12, 2016	Los Alamos National Laboratory Center for Nonlinear Studies: “Capturing multiple states of a molecular machine by cryo-EM”
May 25, 2016	Lecture at Cornell University
June 19-24, 2016	Gordon Research Conference, Hong Kong: “Milestones in single-particle cryo-EM”
June 27-29, 2016	9 th Kuo Symposium, Gubei Water Town. Keynote Lecture: “Single-particle cryo-EM at 2-3 Å resolution – a dream come true. But what is next?”
July 6-10, 2016	Ribosome Meeting, Strasbourg, France: “The Structure of the <i>T. cruzi</i> ribosome at 2.5 Å resolution: insights into the “repair” of the fragmented 28S rRNA and the locations of methylation sites.”
October 20, 2016	Seminar at Cold Spring Harbor: TBA.
December 5-6, 2016	External examiner for evaluation of Johns Hopkins University’s Department of Biophysics.
January 19, 2017	University of California at San Francisco, BBC Seminar series Invited seminar presentation: TBA