Sol Michael Gruner

The John L. Wetherill Emeritus Professor of Physics Emeritus, Cornell University

Background:

Massachusetts Institute of Technology	S.B.	1972	Physics
Princeton University	Ph.D.	1977	Physics
Princeton University, Assistant Professor			1978-1985
Princeton University, Associate Professor			1985-1991
Exxon Research, Research & Engineering, Visiting Fellow			1986
Institute for Theoretical Physics, University of California at Santa Barbara, Visiting Appointment			Fall 1989, Fall 1994
Princeton University, Professor			1991-1997
Robert Wood Johnson Medical School, Dept. of Pathology, Visiting Appointment			1994-1995
Cornell University, Professor, Dept. of Physics			1997-
Director, Cornell High Energy Synchrotron Source (CHESS)			1997-2013
Assoc. Direc., Cornell Lab for Accelerator-based ScienceS and Education (CLASSE)			2011-2013
Emeritus Professor of Physics, Cornell University			2020

Honors and Activities:

Phi Beta Kappa; Sigma Xi	
Danforth Foundation Fellowship	1972-1976
Fellow, American Physical Society	1990
Fellow, American Association for the Advancement of Science	2001
Member, American Academy of Arts & Sciences	2011

Founding Member, Collaborator, and Technical Advisor, ECR/PRT on X-9, NSLS	1979
Chairman, NSLS Users Subgroup on Time-Resolved Diffraction	1982
Scientific Advisory Board, The Liposome Co.	1983
Co-Chairman of 2nd and 3rd Biannual Princeton-Liposome Research Conference on Lipid Membranes	1985 and 1987
Editorial Board, Journal of Liposome Research	1988; 1998-2005
Scientific Advisory Board, Enzymatics Co.	1988-1990
Editorial Board, *Review of Scientific Instruments*	1990-1992
Member at Large, Div. Biol. Physics, Amer. Phys. Soc.	1990
Organizer and Executive Board Member of Princeton Materials Institute	1990
Dept. of Energy Health & Environ. Res. Advisory Subcommittee, Structural Biology	1992
Publications Committee, *Biophysical Journal*	1993-1994
Editorial Board, *Internat. Series in Basic and Appl. Biol. Physics* (AIP Press)	1994-1996
Program Committee, Synchrotron Radiation Instr. '95 conference	1995
NIH BioCARS Advisory Committee (APS Synchrotron)	1994
CMC-CAT Executive Committee (APS Synchrotron)	1995-1997
Assoc. Faculty, Princeton Environmental Institute	1996-1997
Member-at-Large, SAXS Special Interest Group, ACA	1997
International Advisory Committee, Synchrotron Radiation Instrumentation (SRI-2000)	1997
Dept. of Energy Basic Energy Sciences Advisory Subcommittee (Birgeneau Report)	1998
SLAC Scientific Policy Committee	1999-2002
International Union of Crystallography Commission on High Pressure	1998-2002
Chair, NSLS Scientific Advisory Committee	1999-2004
NRC Solid State Sciences Committee (Chair from 2001)	1999-2003
NRC Board of Assessment of NIST	1999-2002
International Union of Crystallography Commission on Synchrotron Radiation	1999-2008
Univ. Chicago APS Review Committee	2003

NSF MPS Scientific Advisory Committee	2004-2007
Scientific Council, DESY, Hamburg, Germany	2005-2007
Program Committee, ICFA workshop on future light sources	2009
SSRL Science Advisory Committee	2011-2013
European XFEL Detector Advisory Committee	2011-2013
Advisory Editorial Board, *Structural Dynamics*	2013-2020
Advisory Committee, Center for Exploration of Energy & Matter, Indiana Univ.	2014-2018
Helmholtz Organization, Germany, "From Matter to Materials and Life" review panel and vice-chair of the photon sub-panel	2014
Dynamic Compression Sector (APS) Scientific Working Group	2015-
LCLS Detector Advisory Group, SLAC	2016-2018
Rochester Inst. Tech., School of Physics & Astronomy, Advisory Board	2017-
Helmholtz Organization, Germany, Review of Karlsruhe Inst. Tech., Research Field Matter	2018
Guinness World Record: Highest resolution electron microscope image	2018
Microscopy Today Innovation Award for EMPAD	2019

Patents:

S.M. Gruner and G. Kirk. Encapsulated scintillators for measuring the concentration of tritiated solutes. U.S. Patent #4,588,698 (5/13/86).

Robert P. Lenk, Michael W. Fountain, Andrew S. Janoff, Mircea C. Popescu, Steven J. Weiss, Richard S. Ginsgurg, Marc J. Ostro & Sol M. Gruner, Stable plurilamellar vesicles. US Pat. 5030453 - Filed Oct 12, 1984.

Robert P. Lenk, Michael W. Fountain, Andrew S. Janoff, Mircea C. Popescu, Steven J. Weiss, Richard S. Ginsgurg, Marc J. Ostro & Sol M. Gruner, Stable plurilamellar vesicles. US Pat. 5169637 - Filed Apr 2, 1991.

K. McGrath, D.M. Dabbs, I.A. Aksay, S.M. Gruner. Lyotropic liquid crystalline L_3 phase silicated nanoporous monolithic composites and their production. U.S. Patent # 6,638,885 (10/28/03).

Chae Un Kim & Sol M. Gruner, "Pressure Cryocooling Protein Crystals", U.S. Patent 8030449 B2, granted Oct. 4, 2011.

Professional Societies:

American Physical Society
Biophysical Society
American Assoc. for Advancement of Science
American Crystallographic Assoc.

Publications & Students (as of 5/15/2021):

- Mentored 36 students through to the PhD, and 26 post-docs.
- Authored 367 publications. The Institute for Scientific Information lists 16,990 citations, and an h-index of 70; Google Scholar lists 24,646 citations and an h-index of 8l.

Narrative: Major Research Thrusts & Accomplishments

Phase Behavior of Biomembrane Lipids

Studies on the phase behavior of biomembrane lipids occupied Gruner's attention through the decade of the 1980's. He was responsible for introducing concepts of elasticity from liquid crystal physics as applied to lipid monolayers to understand the mesomorphic behavior of lipid-water dispersions. Gruner and graduate student G. Kirk introduced the concept that lipid mesomorphic behavior may be understood as a frustrated system dominated by lipid monolayer spontaneous curvature and hydrocarbon chain packing. (Similar ideas were introduced independently at about the same time by J. Charvolin in France). In 1985 Gruner proposed that lipid monolayer spontaneous curvature is a homeostatically controlled parameter in biomembranes, and that monolayer elastic strain couples to membrane protein function [1]. He also studied lipid cubic phases and coined the widely used suggestive name "Plumbers Nightmare" for cubic phases of certain symmetry. In 1988, Gruner and colleagues showed how spontaneous curvature and chain packing can explain bicontinuous cubic phases in mesomorphic systems [2]. Much of the now commonly used language about lipid spontaneous curvature in the biophysical literature can be traced to Gruner's publications of this period; this work is summarized in [3]. In 1990, Gruner was named a Fellow of the American Physical Society "For major contributions to the understanding of structure and function of biomembranes. His research has provided insight on the physical basis of lyotropic mesomorphism."

Block Co-Polymer Phase Behavior and Co-Polymer Based Synthesis of Complex Materials

In 1986 Gruner spent a sabbatical year at Exxon Research & Engineering and became interested in block copolymers. He realized that the same phenomenological physics that controlled lipid and surfactant phase behavior can be used to understand mesomorphism in block copolymers. Gruner and graduate student D. Hajduk began a series of systematic investigations of block co-polymer behavior using x-ray diffraction. In 1994 they discovered the block co-polymer gyroid morphology [4]. The concepts were later extended by Matsen and Bates others to explain copolymer phase diagrams [5]. This work set the stage for a rapid expansion of discoveries in block copolymer physics and materials science.

Gruner continues co-polymer investigations to the present day. Since coming to Cornell in 1997, he has collaborated with the Ober and Wiesner groups in Cornell's Materials Science & Engineering Department to study block copolymer-based synthesis of complex morphologies. These include morphologies where the block domains are chemically altered into metals and metal oxides, or chemically removed to create mesoporous structures. The work has been very productive, resulting in over three dozen publications and contributing to many Ph.D. projects (see http://bigbro.biophys.cornell.edu/publications/). A recent development been the synthesis of a completely new class of self-assembled superconductor materials [6].

X-ray and Electron Microscope Detectors

Gruner has been working on the development of quantitative imaging x-ray detectors since his undergraduate thesis (1972), which was on the fabrication of one of the first silicon pixel array detectors for ionizing radiation detection. Early detectors at Princeton were based upon combinations of phosphors, image intensifiers and cooled imagers derived from astrophysics. In 1986 Gruner published on one of the first x-ray imagers using a CCD array [7]. In the early 1990's his group collaborated with CHESS to build and install the first CCD x-ray detector for macromolecular crystallographic data collection at a synchrotron facility. This device, which was based on phosphor films coupled to a cooled CCD via a fiber optic taper, catalyzed an exponential growth (literally) in macromolecular structure determination, and enabled experiments that would be difficult to otherwise perform. As example, a CCD detector constructed by Gruner's group was used by Rod MacKinnon (Rockefeller Univ.) to solve the structure of the K+ channel [8], which was listed by *Science* as one of the most important accomplishments of 1998, and which won the MacKinnon the Nobel prize in chemistry in 2003. In 1999 Gruner was invited to summarize the development of these detectors at the American Crystallographic Society [9]. By 2012 the majority of macromolecular structures deposited in the Protein Data Bank were determined using CCD detectors utilizing technology first demonstrated in Gruner's laboratory and then outsourced to industry.

Emphasis then shifted to silicon Pixel Array Detectors (PADs) in which x-rays are directly captured and the resultant signals processed in integrated circuit chips. Gruner's group designed and applied the world's first PADs for synchrotron science experiments. These have been applied to, e.g., the study of gaseous shock waves, fuel injected aerosols, and phase transformation in reactive metal foils [10-14]. Gruner is especially proud of students and colleagues who were trained in the group on the PAD work. For example, colleague

Eric Eikenberry, who was a member of the group for almost 15 years, went on to help develop the Pilatus line of detectors and to co-found Dectris, presently one of the largest vendors of scientific PADs. Graduate student Sandor Barna and post-doc Guiseppe Rossi went on to industry and, with Eric Fossum, helped to develop some of the first practical CMOS cell phone cameras.

Other personnel in the laboratory, including colleagues Drs. Mark Tate, Hugh Philipp, and Kate Shanks have specialized on integrating PADs (as opposed to photon counters) suitable for very fast time-resolved experiments. The lab is recognized as a world leader in this technology. For example, the group designed the CS-PAD chips installed at experimental stations at the SLAC Linac Coherent Light Source (LCLS), the world's first hard x-ray free electron laser. CS-PADs have been used to collect the great majority of LCLS data. An example is one of the first LCLS serial protein crystallography experiments [15]. Another was cited by *Science* as one of the most important experiments of 2012 [16]. Several other PADs are in development for a wide variety of synchrotron x-ray experiments.

PAD technology developed in Gruner's lab is now also being adapted for electron microscopy [17], resulting in work that, for example, set a new world resolution record [18, 19], and won a 2019 *Microscopy Today* innovation Award [30]. The technology is being vended by the electron microscope division of ThermoFisher Scientific.

High Pressure Effects on Macromolecules

A paradigm shift is occurring in the biological sciences with the startling realization over the last few decades that a significant fraction, and arguably a majority of the biomass on Earth exists in deep, high pressure environments that were formerly thought to be inhospitable, if not sterile. Pressures of up to a few thousand atmospheres are present in the biosphere and have long been known to have dramatic effects on numerous biomolecular systems. A better understanding of high pressure biophysics will be central to the rapidly emerging view of the high pressure evolution of life on Earth. However, pressure effects are poorly understood, largely because of a lack of tools and techniques suitable to determine the effects of pressure on biomacromolecular structure. Recognizing this, Gruner's approach over the last 25 years has been to develop x-ray tools and methods for macromolecular structure determination at high pressure under biologically relevant conditions [20-23]. The effects of pressure turn out to lend considerable insight into the functioning of proteins and macromolecular systems. Some examples may be found in [22, 24-26]. In 2019 the NSF funded a unique beamline at CHESS specifically for biophysical studies of the effects of pressure on macromolecules. Gruner was the major advocate and designer of this effort, which will be unique in the Western hemisphere.

Synchrotron Radiation Technology and Science

As principle investigator and director of CHESS from 1997 to 2013, Gruner had been privileged to influence synchrotron radiation science and technology. In 2001 he was named a Fellow of the American Association for the Advancement of Science "For pioneering contributions to the study of biological systems using advanced techniques of x-ray physics and for leadership in the development of synchrotron radiation instrumentation." Detectors and high-pressure x-ray techniques mentioned above are examples. Other examples are less apparent, but none the less significant, including fostering talent among colleagues at Cornell and CHESS to develop new technology. Examples include microfabricated flow cells [27], x-ray multilayers [28], and confocal x-ray microscopy as applied to works of art [29]. He was also principle investigator of Cornell's Energy Recovery Linac (ERL) project, which sought to develop a novel type of diffraction limited synchrotron x-ray source [30].The feasibility of an ERL was successfully demonstrated. However, the construction of a major x-ray facility is a political decision that has yet to be resolved because large scale synchrotron x-ray facilities cost the better part of $1B.

In 2011 Gruner was elected to the American Academy of Arts and Sciences in recognition of his contributions.

1. Gruner, S.M., *Intrinsic Curvature Hypothesis for Biomembrane Lipid-Composition - a Role for Nonbilayer Lipids.* Proceedings of the National Academy of Sciences of the United States of America, 1985. **82**(11): p. 3665-3669.
2. Anderson, D.M., S.M. Gruner, and S. Leibler, *Geometrical aspects of the frustration in the cubic*

phases of lyotropic liquid crystals. Proceedings of the National Academy of Sciences, 1988. **85**(15): p. 5364-5368.

3. Gruner, S.M., *Stability of Lyotropic Phases with Curved Interfaces.* Journal of Physical Chemistry, 1989. **93**(22): p. 7562-7570.
4. Hajduk, D.A., et al., *The gyroid: A new equilibrium morphology in weakly segregated diblock copolymers.* Macromolecules, 1994. **27**(15): p. 4063-4075.
5. Matsen, M. and F.S. Bates, *Unifying weak-and strong-segregation block copolymer theories.* Macromolecules, 1996. **29**(4): p. 1091-1098.
6. Robbins, S.W., et al., *Block copolymer self-assembly–directed synthesis of mesoporous gyroidal superconductors.* Science advances, 2016. **2**(1): p. e1501119.
7. Eikenberry, E.F., S.M. Gruner, and J.L. Lowrance, *A Two-Dimensional X-Ray-Detector with a Slow-Scan Charge-Coupled Device Readout.* Ieee Transactions on Nuclear Science, 1986. **33**(1): p. 542-545.
8. Doyle, D.A., et al., *The structure of the potassium channel: molecular basis of K+ conduction and selectivity.* Science, 1998. **280**(5360): p. 69-77.
9. Gruner, S.M., *Synchrotron Radiation and Detectors: Synergists in a Dance.* Transactions ACA, 1999. **34**: p. 11-25.
10. Trenkle, J.C., et al., *Time-resolved x-ray microdiffraction studies of phase transformations during rapidly propagating reactions in Al/Ni and Zr/Ni multilayer foils.* Journal of Applied Physics, 2010. **107**(11).
11. Liu, X., et al., *Four dimensional visualization of highly transient fuel sprays by microsecond quantitative x-ray tomography.* Applied Physics Letters, 2009. **94**(8): p. 084101.
12. Im, K.S., et al., *Interaction between Supersonic Disintegrating Liquid Jets and Their Shock Waves.* Physical review letters, 2009. **102**(7): p. 074501.
13. Cai, W.Y., et al., *Quantitative analysis of highly transient fuel sprays by time-resolved x-radiography.* Applied Physics Letters, 2003. **83**(8): p. 1671-1673.
14. MacPhee, A.G., et al., *X-ray imaging of shock waves generated by high-pressure fuel sprays.* Science, 2002. **295**: p. 1261-1263.
15. Boutet, S., et al., *High-Resolution Protein Structure Determination by Serial Femtosecond Crystallography.* Science, 2012. **337**(6092): p. 362-364.
16. Koopmann, R., et al., *In vivo protein crystallization opens new routes in structural biology.* Nature Methods, 2012. **9**(3): p. 259-U54.
17. Tate, M.W., et al., *High Dynamic Range Pixel Array Detector for Scanning Transmission Electron Microscopy.* Microscopy and Microanalysis, 2016. **22**: p. 237-249.
18. Jiang, Y., et al., *Electron ptychography of 2D materials to deep sub-ångström resolution.* Nature, 2018. **559**(7714): p. 343-349.
19. Rodenburg, J., *A record-breaking microscope.* Nature, 2018. **559**: p. 334-335.
20. Kim, C.U., et al., *Evidence for liquid water during the high-density to low-density amorphous ice transition.* Proceedings of the National Academy of Sciences of the United States of America, 2009. **106**(12): p. 4596-4600.
21. Ando, N., et al., *Structural and Thermodynamic Characterization of T4 Lysozyme Mutants and the Contribution of Internal Cavities to Pressure Denaturation.* Biophysical Journal, 2009. **96**: p. 331.
22. Urayama, P., G.N. Phillips, and S.M. Gruner, *Probing substates in sperm whale myoglobin using high-pressure crystallography.* Structure, 2002. **10**(1): p. 51-60.
23. Collins, M.D., C.U. Kim, and S.M. Gruner, *High-Pressure Protein Crystallography and NMR to Explore Protein Conformations*, in *Annual Review of Biophysics, Vol 40*, D.C. Rees, K.A. Dill, and J.R. Williamson, Editors. 2011. p. 81-98.
24. Barstow, B., et al., *Alteration of citrine structure by hydrostatic pressure explains the accompanying*

spectral shift. Proceedings of the National Academy of Sciences of the United States of America, 2008. **105**(36): p. 13362-13366.

25. Collins, M.D., et al., *Structural rigidity of a large cavity-containing protein revealed by high-pressure crystallography.* Journal of Molecular Biology, 2007. **367**(3): p. 752-763.

26. Ando, N., et al., *Pressure unfolding of a large cavity mutant of T4 Lysozyme.* Biophysical Journal, 2007: p. 400A-400A.

27. Pollack, L., et al., *Compactness of the denatured state of a fast-folding protein measured by submillisecond small-angle x-ray scattering.* Proceedings of the National Academy of Sciences of the United States of America, 1999. **96**(18): p. 10115-10117.

28. Kazimirov, A., et al., *Multilayer X-ray optics at CHESS.* Journal of Synchrotron Radiation, 2006. **13**: p. 204-210.

29. Woll, A., et al., *Development of confocal X-ray fluorescence (XRF) microscopy at the Cornell high energy synchrotron source.* Applied Physics A: Materials Science & Processing, 2006. **83**(2): p. 235-238.

30. Bilderback, D.H., et al., *Energy recovery linac (ERL) coherent hard x-ray sources.* New Journal of Physics, 2010. **12**.