TONY F. HEINZ

Professor of Applied Physics, Photon Science, and, by courtesy, of EE http://heinz.stanford.edu
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Education

B.S. Physics (with Distinction), Stanford University, 1978
Ph.D., Physics, University of California, Berkeley, 1982

Professional Experience

Stanford University and SLAC National Accelerator Laboratory:
Professor of Applied Physics, Photon Science, and, by courtesy, of Electrical Eng., Stanford, 2015 -
Associate Laboratory Director for Energy Sciences, SLAC, 2017 - 2022
Director, Chemical Science Division, SLAC, 2015 – 2019
Columbia University:
Professor of Physics and Electrical Engineering, 1995 - 2000, David Rickey Professor, 2001 – 2014
Chair, Dept. of Electrical Engineering, 2003 - 2007
IBM Research Division, T. J. Watson Research Center, Yorktown Heights, NY:
Research Staff, 1983 – 87; Dept. Manager, 1987 – 93; Senior Department Manager, 1993 - 95

Honors

Levine Award for Outstanding Studies in Physics, Stanford University, 1978
National Science Foundation Graduate Fellow, UC Berkeley, 1978 - 81
IBM Graduate Fellow, University of California, Berkeley, 1982 - 83
IBM Outstanding Technical Achievement Award, 1992, and Invention Award, 1994
International Commission for Optics Prize; Ernst Abbe Medal, 1995
Alexander von Humboldt Research Award, Germany, 1996
Great Teacher Award, Columbia University, 2005
Julius Springer Prize for Applied Physics (with Phaedon Avouris), 2008
Frank Isakson Prize, American Physical Society, 2014
Gordon and Betty Moore Foundation EQiPS Investigator, 2014-2019, 2020-2026
Clarivate Citation Laureate in Physics, 2019
William F. Meggers Award, Optical Society of America, 2020
Medard Welch Award, American Vacuum Society, 2021
Arthur L. Schawlow Prize in Laser Science, American Physical Society, 2022
IEEE NTC Pioneer Award in Nanotechnology, 2024
ACS Ahmed Zewail Award in Ultrafast Science and Technology, 2025
Optica Frederick Ives Medal /Jarus Quinn Prize, 2026
ACS Louis E. Brus Award in Nanoscience and Nanotechnology, 2026
Fellow: APS, American Vacuum Society, IEEE, Optica, MRS, AAAS; Member, NAS

Selected Professional Activities

Editor, *Journal of the Optical Society of America B* (*JOSA B*), 1994 - 2000
Chair, Review Panel, NIST Optical Technology Division, Physics Laboratory, 2000-2005
Chair, Division of Laser Science of the American Physical Society, 2001-2
Chair, Quantum Electronics and Laser Science Conference, QELS, 1995
Chair, International Conference on Quantum Electronics, IQEC, 2002
Chair, Board of Editors, Optical Society of America, 2005 - 2009
Chair, Gordon Conference on Ultrafast Dynamics of Cooperative Phenomena, 2010
Scientific Director, NSF Nanoscale Science & Engineering Center at Columbia, 2006 – 2012
Scientific Director, DOE Energy Frontier Research Center at Columbia, EFRC, 2009 – 2014
President, Optical Society of America, 2012
Chair, Scientific Advisory Board, Center for Integrated Nanotechnology, CINT, Sandia-LLNL, 2011-2016
Chair, Subcommittee on Optics and Photonics, NSF Dir. of Math and Physical Science, 2013- 2015
Founding Editor, North America, *2D Materials* journal 2014-2017; Editorial Board 2018 -
Co-Chair, DOE Roundtable on Frontiers of Ultrafast X-ray Science, 2016-17
Scientific Advisory Boards: Institute of Science and Technology, Austria, 2013-, Fritz-Haber Institute, Berlin, 2014-2023; Max-Born Institute, Berlin, 2014-2023; and many national programs

Publications: >340 papers in refereed journals; >129,000 citations; >8,700 in 2025; H-index 142 (Google scholar) Clarivate highly cited author, 2015 – 25; Citation Laureate in Physics, 2019 (1 of 3)

Patents: 20 US patents issued

SELECTED PROFESSIONAL ACTIVITIES FOR TONY F. HEINZ

- Topical Editor, *Journal of the Optical Society of America B: Optical Physics,* 1987 – 1993
- Program Committee, International Quantum Electronics Conference (IQEC), 1987, 1988, 1990, 1998, 2000
- Program Committee, Quantum Electronics & Laser Science Conference (QELS), 1989, 1991, 1992, 2007
- Review Board, National Science and Engineering Council of Canada, 1991-94
- Program Committee, Int'l Conference on Coherent and Nonlinear Optics, 1991, 1995, 1997, 1999
- Program Committee, Optical Society of America Annual Meeting, 1992, 1994, 1998
- Program Chair, Quantum Electronics and Laser Science Conference, 1993
- Program Committee, Interdisciplinary Laser Science Conference, 1993
- Review Panel, Materials Science Program, US Department of Energy, 1993
- Visiting Professor, Technical University of Vienna, Austria, 1994
- Symposium Organizer, Materials Research Society, 1994
- Committee on Atomic, Molecular and Optical Physics, National Research Council, 1994 – 97
- Editor, *Journal of the Optical Society of America B: Optical Physics,* 1994 – 2000
- General Chair, Quantum Electronics and Laser Science Conference, 1995
- Chair, Joint Council on Quantum Electronics of IEEE/OSA/APS, 1995 – 98
- Organizer, International Workshop on Nonlinear Optics of Semiconductor Surfaces, Garching, Germany, 1996.
- Chair, Optical Sciences Division, Optical Society of America, 1996 – 98
- Advisory Board, Gordon Conf. on Molecular Electronic Spectroscopy & Dynamics, 1996, 1998
- Chair, Faculty Search Committee for Condensed Matter Physics, Columbia University, 1996 – 98; 2000 – 01
- Review Panel, Los Alamos National Laboratory, 1998, 2001
- Board of Directors, Optical Society of America, 1998 – 2001; 2001– 2004; 2006 – 2009

- Program Committee, The Eighth International Workshop on Desorption Induced by Electronic Transitions DIET, 1999
- Chair, Graduate Admission Committee, Dept. of Physics, Columbia University, 1999 – 2000, 2001– 02
- Review Panel, Physics Laboratory, National Institute of Science and Technology NIST, Gaithersburg, MD, 1999 – 2005
- Program Co-Chair, OSA Nonlinear Optics 2000 Conference
- Chair Elect, Division of Laser Science, American Physical Society, 2000
- Symposium Organizer, March Meeting of the American Physical Society, 2000
- Director, Adriatico Symposium on Laser Applications in Surface Science, International Center for Theoretical Physics, 2000
- Chair, Technical Council, Optical Society of America, 2000 – 2001
- Frank Isakson Prize Selection Committee, American Physical Society, 2000 – 2002
- Vice-Chair, Division of Laser Science, American Physical Society, 2001
- Frederick Ives Prize Selection Committee, Optical Society of America, 2001 – 2003
- Executive Committee, NSF Columbia Nanoscale Science and Engineering Center (NSEC), Columbia University, 2001 – 2012
- Program Committee, IEEE Lasers and Electro-Optics Conference, LEOS 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010
- Chair, Division of Laser Science, American Physical Society, 2002
- General Co-Chair, OSA Nonlinear Optics 2002 Conference
- Program Co-Chair, International Quantum Electronics Conference (IQEC), 2002
- Program Committee, Ultrafast Optics Conference, 2002, 2005
- Chair, Department of Electrical Engineering, Columbia University, 2003 – 2007
- Tenure Review Advisory Committee, Columbia University, 2004 – 2007
- Great Teacher Award of the Society of Columbia Graduates, Columbia University, 2005
- Sub-Panel Chair, Department of Energy Workshop on Solar Energy, 2005

- Co-Chair, International Conference on Coherent and Nonlinear Optics ICONO, St. Petersburg, Russia, 2005

- Program Committee, Seventh International Conference on the Science and Application of Nanotubes, Nagano, Japan, 2006

- Co-Chair, Workshop on Nanostructure Interfaces, Brookhaven National Lab, 2006

- Chair, Diversity Faculty Search, Dept. of Physics, Columbia University, 2006 – 2007

- Chair, Board of Editors, Optical Society of America, 2005 – 2009

- External Advisory Committee, Institute of Physics, Beijing, 2006 – 2009

- Co-Organizer, DOE Materials Council Study on Ultrafast Material Science, 2007

- Scientific co-Director (with Ron Breslow), NSF Nanoscale Science and Engineering Center NSEC, Columbia University, 2007 – 2012. (Budget: $16 M)

- Chair, Faculty Search Committee, Dept. of Electrical Engineering, Columbia University, 2007-2009, 2010 – 2011

- Provost's Diversity Committee, Columbia University 2007 – 2009

- Member, Publications Ethics Review Committee, Optical Society of America, 2007– 2010

- Science Advisory Committee, National Synchrotron Light Source, Brookhaven National Laboratory, 2007– 2011

- Advisory Board, Department of Electrical and Computer Engineering, Rice Univ., 2007 – 2012

- External Review Board, Nanoscience Program, Jülich Laboratory of the Frauenhofer Society, Germany, 2008

- Program Committee, Ninth International Conference on the Science and Application of Nanotubes, Montpellier, France, 2008

- Co-Organizer, APS March Meeting Focus Session on Nanotubes and Related Materials, New Orleans, LA 2008

- Vice-Chair, Gordon Conference on Ultrafast Dynamics of Cooperative Systems, 2008

- Program Committee, Conference on Ultrafast Surface Dynamics, Kloster Banz, Germany, 2008

- External Review Board, Munich Photonics Center of Excellence, Munich, Germany, 2008 –

- Provost's Science Planning and Review Committee, Columbia University, 2008 – 2009

- Search Committee for Provost, Columbia University, 2008 – 2009

- Co-Organizer, APS March Meeting Focus Session on Nanotubes and Related Materials, Pittsburgh, PA 2009

- Program Committee, Tenth International Conference on the Science and Application of Nanotubes, Beijing, China, 2009

- Scientific co-Director (with Louis Brus), DOE Energy Frontier Research Center EFRC, Columbia University, 2009-2014 (Budget: $18M)

- Program Committee, International Winter School on Electronic Properties of Novel Materials, 2009, 2011, 2012, 2014, 2015, 2016, 2018

- Chair, Gordon Conference on Ultrafast Dynamics of Cooperative Systems, 2010

- Program Committee, Graphene Symposium for Eleventh International Conference on the Science and Application of Nanotubes, Montreal, Canada, 2010

- Vice President, Optical Society of America, 2010

- President Elect, Optical Society of America, 2011

- Program Committee, Graphene 2011, Bilbao, Spain, 2011

- Advisory Board, Twelfth International Conference on the Science and Application of Nanotubes, Cambridge, England, 2011

- Program Committee, International Winter School on Electronic Properties of Novel Materials, 2011

- Visiting Professor, École Polytechnique Fédérale de Lausanne EPFL, Switzerland, 2011.

- Chair, Scientific Advisory Board, Center for Integrated Nanotechnologies, CINT, Los Alamos National Laboratory – Sandia National Laboratories, 2011 – 2016

- President, Optical Society of America, 2012

- Advisory Board, Thirteenth International Conference on the Science and Application of Nanotubes, Brisbane, Australia, 2012

- Search Committee for Dean of Engineering, Columbia University, 2012

- Faculty Oversight Committee, Columbia Mind, Brain, Behavior Initiative, Columbia University, 2012-2014

- Co-Director, Center for Integrated Science and Engineering CISE, Columbia University, 2012-2014

- Program Committee, International Conference on Ultrafast Phenomena, 2012, 2014, 2016

- Past President, Optical Society of America, 2013
- Program Committee, Conference on Ultrafast Surface Dynamics, Estes Park, CO, 2013
- Program Committee, Graphene Week, Chemnitz, Germany, 2013
- Chair, Subcommittee for Optics and Photonics, NSF Directorate of Mathematical and Physical Science, 2013 – 2015
- International Scientific Board, Institute of Science and Technology, Austria, 2013 –
- Scientific Advisory Board, Fritz-Haber Institute, Berlin, Germany, 2014 – 2023
- Scientific Advisory Board, Max-Born Institute, Berlin, Germany, 2014 – 2023
- Max-Born Awards Committee, Optical Society of America, 2015 – 2016.
- Organizer of symposium on properties and growth of 2D materials, APS March Meeting 2017, New Orleans, LA, 3/13 – 3/17/17.
- Founding Editor, North America, *2D Materials,* new journal published by the Institute of Physics in response to emergence of this research area, 2014 – 2018.
- Co-chair, DOE Roundtable on Frontiers of X-ray Ultrafast Science, 2016 – 17.
- Scientific Advisory Committee, Center for Computational Study of Excited-State Phenomena in Energy Materials - C2SEPEM, University of California, Berkeley, Lawrence Berkeley National Laboratory, 2016 –
- Chair, search committee, Photon Sciences Dept., SLAC/Stanford, 2017 – 2019
- Scientific Advisory Committee, Center of the Advancement of Topological Semimetals (CATS) Energy Frontier Research Center, Ames Laboratory, 2017 –
- Scientific Advisory Committee, Center for Novel Pathways to Quantum Coherence Energy Frontier Research Center, University of California, Berkeley, Lawrence Berkeley National Laboratory, 2017 – 2023
- Editorial board, *2D Materials,* 2018 –
- Strategic planning committee for the natural sciences, Stanford University, 2018 – 19
- Executive committee, Q-FARM quantum information science center, Stanford 2019–
- AAAS Electorate Nominating Committee ENC (Sect. B), 2019 – 2022
- Faculty search committee for quantum information science, Stanford University, 2020 – 2021
- DOE workshop on the quantum internet blueprint workshop, 2020

- Scientific Advisory Board, DOE QIS Center: Co-Design Center for Quantum Advantage, 2020-
- Scientific Advisory Board, Center for Electrochemical Dynamics and Reactions at Surfaces (CEDARS), DOE Energy Frontier Research Center, North Carolina A&T State University, 2022 –
- Graduate Committee, Dept. of Applied Physics, Stanford, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
- Selection Committee, Stanford Science Fellows, Stanford, 2023
- Graduate Admissions Committee, Dept. of Applied Physics, Stanford, 2023 – 24.
- Member, Faculty Senate, Stanford, 2022 – 23, 2023 – 24
- Member, Committee of Atomic, Molecular, and Optical Sciences, National Academies of Sciences, Engineering, and Medicine, 2024 –
- Member, Proposal Review Pannel, Ultrafast Electron Diffraction, LCLS, SLAC, 2024
- Member, Executive Committee, Stanford Science Fellows, Stanford 2024 –
- Academic Council Committee on Research (C-Res), Stanford, 2024 – 25, 2025 – 26
- Director of Graduate Studies, Department of Applied Physics, Stanford, 2024 – 25, 2025 – 26
- Chair, Search Committee for Energy Sciences Associate Laboratory Director, SLAC, 2024 – 25
- Scientific Advisory Board, New York Max Planck Center, 2021 – 2024, 2024 –
- Faculty Director, E. L. Ginzton Laboratory, Stanford, 2026 –

HONORS AND DISTINCTIONS FOR TONY F. HEINZ

- Levine Award for Outstanding Studies in Physics, Stanford University, 1978
- National Science Foundation Graduate Fellow, UC Berkeley, 1978 – 81
- Hertz Graduate Fellowship (declined), 1978
- IBM Graduate Fellow, University of California, Berkeley, 1982 - 83
- IBM Outstanding Technical Achievement Award, 1992, and Invention Award, 1994
- International Commission for Optics Prize; Ernst Abbe Medal, 1995
- Alexander von Humboldt Research Award, Germany, 1996
- Great Teacher Award, Columbia University, 2005
- Julius Springer Prize for Applied Physics (with Phaedon Avouris), 2008
- Gordon and Betty Moore Foundation EPiQS Investigator, 2014-19
- Frank Isakson Prize, American Physical Society, 2014
- Clarivate 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025 highly cited in Physics
- Clarivate Citation Laureate 2019 (one of three in physics worldwide)
- Gordon and Betty Moore Foundation EPiQS Investigator, 2020-24
- William F. Meggers Award, Optical Society of America, 2020
- Medard W. Welch Award, American Vacuum Society, 2021
- Arthur L. Schawlow Prize in Laser Science, American Physical Society, 2022
- Named lectures: Bucy Lecture, Texas Tech University, 2023; Crawford Memorial Lecture, University of Pittsburgh, 2023; Condon Lecture, University of Colorado, 2023.
- IEEE NTC Pioneer Award in Nanotechnology, 2024
- ACS Ahmed Zewail Award in Ultrafast Science and Technology, 2025
- Optica Frederick Ives Medal / Jarus Quinn Prize, 2026
- ACS Louis E. Brus Award in Nanoscience and Nanotechnology, 2026
- Fellow, American Physical Society
- Fellow, IEEE
- Fellow, American Vacuum Society
- Fellow, Optica (OSA)
- Fellow, Materials Research Society

- Fellow, American Association for the Advancement of Science (AAAS)
- Member, National Academy of Science

GRADUATE STUDENTS AND POSTDOC ADVISEES FOR TONY F. HEINZ

Doctoral students:

Prof. Ozgur Burak Aslan (Bogazici University, Turkey)

Prof. Joanna Atkin (Dept. of Chemistry, University of North Carolina)

Dr. Elyse Barré (Viavi Solutions, Ottawa, Canada)

Prof. Ioannis Chatzakis (Dept. of Physics and Astronomy, Texas Tech. University)

Ms. Xueqi Chen (Current: Dept. of Physics, Stanford)

Dr. Minda Deng (Apple)

Mr. Danny Ha (Current: Dept. of Chemistry, Stanford)

Dr. Heather Hill (American Physical Society)

Dr. Jenny Hu (Apple, Inc.)

Prof. Zonghai Hu (Dept. of Physics, Beijing University of Posts and Telecommunications, China)

Dr. Charles Kerbage (Convergent Dental)

Dr. Suk Hyun Kim (Seoul National University, Korea)

Dr. Karen Lau (Lumentum, Inc.)

Ms. Julia Lee (Current: Dept. of Applied Physics, Stanford)

Dr. Yilei Li (Kodiak Sciences)

Prof. Chun Hung Lui (Dept. of Physics, UC Riverside)

Prof. Kin Fai Mak (Max-Planck Inst. for Structure and Dynamics of Matter, Hamburg, Germany)

Mr. Pranaav Mahaadev (Current: Dept. of Applied Physics, Stanford)

Dr. Idan Mandelbaum (CACI International)

Mr. Amal Mathew (Current: Dept. of Applied Physics, Stanford)

Prof. Ajay Nahata (Dept. of Electrical Engineering, University of Utah)

Dr. Clara Nyby (Citrine Informatics, Inc.)

Dr. Aidan O'Beirne (Apple)

Dr. Hayn Park (DE Shaw)

Dr. Kate Pistunova (Motional, Inc.)

Mr. Yannick Pleimling (Applied Physics, current)

Dr. Dan Quinn (TFSCG)

Dr. Archana Raja (Staff Scientist, Lawrence Berkeley National Lab)

Dr. Albert Rigosi (Staff Scientist, NIST)

Prof. Jie Shan (Max-Planck Institute for Structure and Dynamics of Matter, Hamburg, Germany)

Dr. Daohua Song (Goldman Sachs)

Dr. Igor Stiopkin (University of Wisconsin)

Prof. Feng Wang (Dept. of Physics, UC Berkeley)

Ms. Jierong Wang (Current: Dept. of Applied Physics, Stanford)

Dr. Yang Wu (Lansdowne Partners)

Prof. Hugen Yan (Dept. of Physics, Fudan University, China)

Dr. Helen Yao (Psi Quantum)

Prof. Xiao-Xiao Zhang (Dept. of Physics, University of Florida, Gainesville)

Dr. Hui Zhou (Brion, Inc.)

Ms. Alexandra Zimmerman (Current: Dept. of Material Science and Eng., Stanford)

Postdoctoral advisees and visitors:

Dr. Andrew Attar (Vescent Photonics)

Prof. Joanna Atkin (Dept. of Chemistry, University of North Carolina)

Prof. Ludwig Bartels (Dept. of Chemistry, UC Riverside)

Prof. Stephane Berciaud (Dept. of Physics, University of Strasbourg, France)

Dr. Albert Biedermann (Dept. of Physics, University of Vienna, Austria)

Dr. Mischa Bonn (Director, Max-Planck Institute, Mainz, Germany)

Prof. Davide Boschetto (ENSTA, Ecole Polytechnique, Paris)

Dr. Florian Budde (McKinsey and Co.)

Mr. Jiuru Chen (Peking University, China)

Prof. Ting Cao (Dept. of Material Science, University of Washington)

Prof. Alexey Chernikov (Technical University of Dresden, Germany)

Prof. Hyunyong Choi (Dept. of Physics, Seoul National University, Korea)

Prof. Keshav Dani (OIST, Japan)

Dr. Jerry Dadap (Dept. of Physics, University of British Columbia)

Dr. Ipshita Datta (Lawrence Livermore National Laboratory)

Prof. Michael Duerr (Dept. of Applied Physics, University of Giessen, Germany)

Dr. Daejin Eom (KRISS, Korea)

Dr. Friederike Ernst (Gnosis.pm, Inc., Germany)

Prof. Laszlo Forro (Dept. of Physics, EPFL, Switzerland)

Dr. Joergen Gladh (FOI Swedish Defense Research Agency, Sweden)

Dr. Claudia Gollner (Photonics Department, Technical University Vienna, Austria)

Dr. Rubaiat Ul Haque (Current: SIMES, SLAC)

Prof. Christian Heide (Dept. of Physics and CREOL, University of Central Florida)

Prof. Tobias Hertel (Dept. of Chemistry, University of Wuerzburg, Germany)

Prof. Ulrich Hoefer (Dept. of Physics, University of Marburg, Germany)

Dr. Markus Huber (Dept. of Physics, University of Regensburg, Germany)

Prof. Libai Huang (Dept. of Chemistry, Purdue University)

Prof. Shengxi Huang (Dept. of Electrical and Computer Engineering, Rice University)

Dr. Markus Huber (University of Regensburg, Germany)

Dr. Giraj Jnawali (Dept. of Physics, University of Cincinnati)

Dr. Alexander Kalamarides (IntelliClear, Inc.)

Dr. Ouri Karni (NTT Research, Sunnyvale, CA)

Mr. Jinjae Kim (Seoul National University, Korea)

Prof. Ernst Knoesel (Dept. of Physics, Rowan University)

Prof. Yuki Kobayashi (Dept. of Chemistry, University of Michigan)

Dr. Holger Lange (Dept. of Chemistry, U. Hamburg, Germany)

Prof. Qitong Li (Dept. of Electrical Engineering, Tsingua University, China)

Prof. Zhiqiang Li (Dept. of Physics, Sichuan University, China)

Prof. Tony Low (Dept. ECE, University of Minnesota)

Prof. Eric Ma (Dept. of Physics, University of California, Berkeley)

Prof. Leandro Malard (Universidade Federal de Minas Gerais, Brazil)

Prof. Janina Maultzsch (Dept. of Physics, U. Erlangen-Nürnberg, Germany)

Prof. Yuhei Miyauchi (Institute of Advanced Energy, Kyoto University, Japan)

Dr. Dietmar Moeller (unknown)

Dr. Judith Prybyla (Lewis School, Princeton)

Dr. Xixi Qin (Current: SUNCAT, Stanford)

Dr. Archana Raja (Molecular Foundry, Lawrence Berkeley National Laboratory)

Prof. Yi Rao (Dept. of Chemistry, Utah State University)

Prof. Georg Reider (Dept. of Electrical Eng., Technical U. Vienna, Austria)

Dr. Henrique Bucker Ribeiro (Corning, Inc)

Dr. Cyrielle Roquelet (ArcelorMittal, France)

Dr. Sami Rosenblatt (IBM Research Division, Yorktown Heights, NY)

Dr. Claudia Ruppert (Dept. of Physics, University of Dortmund, Germany)

Prof. Jie Shan (Max-Planck Institute for Structure and Dynamics of Matter, Hamburg, Germany)

Prof. Viktoryia Shautsova (Dept. of Materials Science, University of Central Florida)

Dr. Marcus Soldemo (Dept. of Physics, Stockholm University, Sweden)

Prof. Julia Staehler (Dept. of Chemistry, Humboldt University, Berlin, Germany)

Dr. Dezheng Sun (Brion, Inc.)

Prof. Takanori Suzuki (Dept. of Physics, National Defense Academy, Japan, retired)

Dr. Monique Tie (Current: Dept. of Applied Physics, Stanford)

Prof. Christophe Voisin (Ecole Normale Supérieure, Paris, France)

Dr. Lutz Waldecker (RWTH Aachen University, Germany)

Prof. Feng Wang (Dept. of Physics, UC Berkeley)

Prof. Han Wang (School of Physical Sciences, ShanghaiTech, China)

Dr. Aniruddha Weling (Triton Systems)

Dr. Martin Wolf (Director, Fritz-Haber Institute, Berlin, Germany)

Dr. Jun Xiao (Dept. of Materials Science and Engineering, University of Wisconsin)

Prof. Omer Yaffe (Dept. of Complex Systems, Weizmann Institute, Israel)

Prof. Jie Yang (Dept. of Chemistry, Tsinghua University, China)

Prof. Ziliang Ye (Dept. of Physics, University of British Columbia, Canada)

Prof. YuMeng You (Dept. of Chemistry, Southeast University, China)

Dr. Leo Yu (Current: Dept. of Applied Physics, Stanford)

Prof. Xiao-Xiao Zhang (Dept. of Physics, University of Florida, Gainesville)

SELECTED RECENT INVITED TALKS FOR TONY F. HEINZ

T. F. Heinz, "Electronic and Vibrational Properties of Few-Layer Graphene," Conference on Fundamental Aspects of Graphene and Other Carbon Allotropes, Kavli Institute for Theoretical Physics Meeting, Santa Barbara, CA, 1/9 – 1/13/12.

T. F. Heinz, "Electronic Interactions and Ultrafast Dynamics in Graphene," Gordon Research Conference on Ultrafast Phenomena in Cooperative Materials, Galveston, TX, 2/19 – 2/24/12.

T. F. Heinz, "Many-Body Effects in the Optical Properties of Graphene," March Meeting of the American Physical Society, Boston, MA, 2/27 – 3/2/12.

T. F. Heinz, "Probing Interactions in Single- and Few-Layer Graphene by Optical Spectroscopy," International Winter School on Electronic Properties of Novel Materials, Kirchberg, Austria, 3/4/ - 3/9/12.

T. F. Heinz, "Seeing Electrons in Two Dimensions: Optical Spectroscopy of Graphene," Physics, Colloquium, MIT, Cambridge, MA 4/5/12.

T. F. Heinz, "Probing Ultrafast Dynamics in Nanoscale Materials by Optical Experiments," Workshop on X-Rays in the Fourth Dimension, Chicago, IL, 5/4 – 5/6/12.

T. F. Heinz, "Probing Electronic Interactions in Graphene by Optical Spectroscopy" Graphene Week 2012, Delft, The Netherlands, 6/3 – 6/8/12.

T. F. Heinz, "Electronic Properties of Single- and Few-Layer Graphene," Gordon Research Conference on Chemistry and Physics of Graphitic Carbon, Davidson, NC, 6/17 – 6/22/12.

T. F. Heinz, "Probing Interactions and Dynamics in Graphene by Optical Spectroscopy," Low-Energy Electrodynamics in Solids LEES 2013, Napa, CA, 7/22 – 7/27/12.

T. F. Heinz, "Seeing Electrons in Two Dimensions: Optical Spectroscopy of Graphene," The Third International Workshop on Nanocarbon Photonics and Optoelectronics, Polvijärvi, Finland, 7/29 – 8/4/12.

T. F. Heinz, "MoS_2 Crystals at Monolayer Thickness - A New Direct Gap Material," 2D Materials beyond Graphene Workshop, Ohio State University, Columbus, OH, 8/8 – 8/9/12.

T. F. Heinz, "Terahertz Spectroscopy of Nanomaterials" Frontiers of Terahertz Science, Stanford University, Stanford, CA, 9/5 - 9/6/12.

T. F. Heinz, "Seeing Electrons in Two Dimensions: Optical Spectroscopy of Graphene," 73rd Japan Society of Applied Physics Autumn Meeting, Matsuyama, Japan, 9/11- 9/14/12.

T. F. Heinz, "Seeing Electrons in Two Dimensions: Optical Spectroscopy of Graphene," International Conference on Applied Optics and Optical Engineering, Changchun, China, 9/16 – 9/18/12.

T. F. Heinz, "Seeing Electrons in Two Dimensions: Optical Spectroscopy of Graphene," Department of Physics, Fudan University, Shanghai, China, 9/20/12.

T. F. Heinz, "Vibrational Spectroscopy of Single- and Few-Layer Graphene," Vibrations at Surfaces VAS14, Kobe, Japan, 9/24 – 9/28/12.

T. F. Heinz, *Plenary Talk:* "Probing the Ultrasmall with the Ultrafast: THz Spectroscopy of Nanomaterials," 37th International Conference on Infrared, Millimeter and Terahertz Waves IRMWW-THz 2012, Wollogong, Australia, 9/23/-9/28/12.

T. F. Heinz, "Optical Spectroscopy of Graphene," American Vacuum Society International Symposium AVS-59, Tampa, FL, 10/28 – 11/2/12

T. F. Heinz, *Plenary Talk:* "Seeing Electrons in Two Dimensions: Optical Spectroscopy of Graphene and MoS_2 Monolayers," ElecMol'12, 6th International Meeting on Molecular Electronics, Grenoble, France, 12/3/ - 12/7/12.

T. F. Heinz, "Seeing Electrons in Two Dimensions: Optical Spectroscopy of Graphene and MoS_2 Monolayers," XFEL Colloquium, DESY, Hamburg, Germany, 12/7/12.

T. F. Heinz, *Plenary Talk*: "Graphene - Optical Properties and Emerging Photonics Technologies,"14th International Meeting on Optical Engineering and Science in Israel, Tel Aviv, Israel, 2/19 -2/20/13.

T. F. Heinz, "Seeing Electrons in Two Dimensions: Optical Spectroscopy of Graphene," Weizmann Institute of Science, Rehovat, Israel, 2/21/13.

T. F. Heinz, "Seeing Electrons in Two-Dimensions: Optical Spectroscopy of Graphene," French-Israeli Symposium on Nonlinear and Quantum Optics, Ein Gedi, Israel, 2/24 – 3/1/13.

T. F. Heinz, "Electronic and Optical Properties of MoS_2 at Monolayer Thickness," International Winter School on the Electronic Properties of Novel Materials, Kirchberg, Austria, 3/2 -3/9/13.

T. F. Heinz, "Seeing Electrons in 2-Dimensions," Physics Colloquium, UC Berkeley, 4/15/13.

T. F. Heinz, "Probing Electronic Interactions in Graphene and MoS_2 by Optical Spectroscopy," Electron-Electron Interactions in Graphene, Minneapolis, 5/3 -5/5/13.

T. F. Heinz, *Tutorial Lecture:* "Optical Properties and Emerging Photonic Applications of Graphene," Conference of Lasers and Electro-optics CLEO, San Jose, CA, 6/9 -6/14/13.

T. F. Heinz, "Optical Spectroscopy of MoS_2," Flatlands Beyond Graphene, Bremen, Germany, 6/17 – 6/21/13.

T. F. Heinz, "Optical Spectroscopy of MoS_2," Workshop on Nanotube Optics and Nanospectroscopy, Santa Fe, NM, 6/16 -6/20/13.

T. F. Heinz, "Excitonic Effects in 2-D Transition Metal Dichalcogenides," Energy Frontier Research Symposium, Washington, DC, 7/18 – 7/19/13.

T. F. Heinz, "Seeing Electrons in Two Dimensions," Gordon Research Conference on Surface Dynamics, Newport, RI, 8/11 – 8/15/13.

T. F. Heinz, Discussion Leader, Gordon Conference on Ultrafast Phenomena in Cooperative Systems, Ventura, CA, 2/2/ - 2/7/14.

T. F. Heinz, "Far-infrared Spectroscopy of Graphene," SPIE Photonics West, San Francisco, CA, 2/3 – 2/7/14.

T. F. Heinz, “Seeing Electrons in Two-Dimensions,” Physics Colloquium, University of Texas, Austin, TX, 2/12/14.

T. F. Heinz, “Seeing Electrons in Two-Dimensions,” Frank Isakson Prize Lecture, March Meeting of the American Physical Society, Denver, CO, 3/3 – 3/7/14.

T. F. Heinz, “Optical Studies of Atomically Thin Transition Metal Dichalogenide Crystals,” Spring Meeting of the Materials Research Society, San Francisco, CA, 4/21 – 4/25/14.

T. F. Heinz, “Excitonic Effects in Atomically Thin Transition Metal Dichalcogenides,” Conference on Excited State Processes in Electronic and Bio Nanomaterials, Santa Fe, NM, 6/9 – 6/12/14.

T. F. Heinz, “Probing Graphene Dynamics by Optical Spectroscopy,” Graphene Week 2014, Gothenburg, Sweden, 6/23 – 6/27/14.

T. F. Heinz, *Plenary talk:* “Optical Spectroscopy of Novel 2D Semiconductors,” IEEE Summer Topical Meeting, Montreal, Canada, 7/14 – 7/17/14.

T. F. Heinz, “Electronic and Optical Properties of Atomically Thin Semiconductors,” Summer School on Semiconductor Interfaces, San Sebastian, Spain, 7/28 – 7/31/14.

T. F. Heinz, “Optical Properties of Atomically Thin Transition Metal Dichalcogenides,” Workshop on 2D Atomic Sheets Beyond Graphene, Army Research Laboratory, Adelphi, MD, 8/12 – 8/13/14.

T. F. Heinz, “Optical Properties of Atomically Thin Semiconductors and Heterostructures,” Rank Prize Funds Symposium on 2D Materials, England, 9/22 – 9/25/14.

T. F. Heinz, *Plenary talk:* “Atomically Thin 2D Semiconductors,” First International Conference on Layered 2-Dimensional Materials, Hangzhou, China, 10/12 – 10/15/14.

T. F. Heinz, "Atomically Thin 2D Semiconductors,” Physics Colloquium, Nanjing University, Nanjing, China, 10/16/14.

T. F. Heinz, “Electronic Properties of Atomically Thin Transition Metal Dichalcogenides,” Conference on Field Effect Transistors and Functional Interfaces, Kawashi, Japan, 10/17 – 10/21/14.

T. F. Heinz, “Optical Spectroscopy of Atomically Thin Semiconductors,” Conference on Physics of Quantum Electronics, Snowbird, UT, 1/4 – 1/8/15.

T. F. Heinz, “Seeing Electrons in 2-Dimensions: Optical Spectroscopy of Atomically Thin Semiconductors,” National High Magnetic Field Laboratory, Tallahassee, FL, 1/13/15.

T. F. Heinz, “Flatlands: The World of Two-Dimensional Materials,” Lecture in Distinguished Speaker Series (for a general audience), University of Central Florida, Orlando, FL, 1/14/15.

T. F. Heinz, “Seeing Electrons in 2-Dimensions: Optical Spectroscopy of Atomically Thin Semiconductors,” Physics Colloquium, University of Central Florida, Orlando, FL, 1/15/15.

T. F. Heinz, “Atomically Thin 2D Materials,” Materials Directorate, Air Force Research Laboratory, Dayton, OH, 1/19/15.

T. F. Heinz, “Seeing Electrons in 2-Dimensions: Optical Spectroscopy of Atomically Thin Semiconductors,” Physics Colloquium, Carnegie Mellon University, Pittsburgh, PA, 1/26/15.

T. F. Heinz, *Plenary Talk:* “2-Dimensional Materials: Graphene and Beyond,” Symposium on the Electronic and Optical Properties of Materials, University of California, Berkeley, CA, 3/7/15.

A. Chernikov and T. F. Heinz, “Excitonic Effects in 2-Dimensional Semiconductors,” International Winter School on the Electronic Properties of Novel Materials, Kirchberg, Austria, 3/8 – 3/14/15.

T. F. Heinz, *Plenary Talk:* “2-Dimensional Materials: Graphene and Beyond,” at the Spring Meeting of the German Physical Society, Berlin, Germany, 3/16 – 3/20/15.

T. F. Heinz, “2-Dimensional Materials: Graphene and Beyond,” Physics Colloquium, Rutgers University, Piscataway, NJ 3/31/15.

T. F. Heinz, “Optical Response of Graphene: From the THz to the UV,” Spring Meeting, Materials Research Society, San Francisco, CA, 4/6 – 4/10/15.

T. F. Heinz, “Many-Body Interactions and Ultrafast Dynamics in 2-D Transition Metal Dichalcogenide Crystals,” Spring Meeting, Materials Research Society, San Francisco, CA, 4/6 – 4/10/15.

T. F. Heinz, “Probing and Tuning the Valley Degree of Freedom in Transition Metal Dichalcogenide Monolayers by the Application of Magnetic Fields,” Spring Meeting, Materials Research Society, San Francisco, CA, 4/6 – 4/10/15.

T. F. Heinz, “Optical Properties of 2-Dimensional Materials: Graphene and Beyond,” Stanford Photonics Research Center Retreat, Pacific Grove, CA, 4/12/15.

T. F. Heinz, “Optical Properties of 2-Dimensional Materials: Graphene and Beyond,” New England Section of the Optical Society of America, Concord, MA, 4/16/15.

T. F. Heinz, “Electronic and Optical Properties of Atomically Thin Transition Metal Dichalcogenide Crystals,” European Union – US Workshop on Layered 2D Materials, Arlington, VA, 4/22- 4/24/15.

T. F. Heinz, *Plenary Talk:* “2-Dimensional Materials: Graphene and Beyond,” Conference on Lasers and Electrooptics CLEO, San Jose, CA, 5/11 – 5/15/15.

Z. Ye and T. F. Heinz, “2-Dimensional Materials: Graphene and Beyond,” 43rd Electronics Materials Symposium, Santa Clara, CA, 5/21 – 5/22/15.

T. F. Heinz, *Plenary Talk:* “2-Dimensional Materials: Graphene and Beyond,” Workshop on Nanotube Optics and Spectroscopy, Kloster Banz, Germany, 6/1 – 6/4/15.

Y. Li and T. F. Heinz, “Addressing and Tuning the Valley Degree of Freedom in Atomically Thin Semiconductors,” CLEO Europe, Munich, Germany, 6/22-6/25/15.

T. F. Heinz, “Optical Properties of Atomically Thin Materials,” Optics of Surfaces and Interfaces (OSI), Austin, TX, 6/29 – 7/3/15.

T. F. Heinz, "2-Dimensional Materials: Graphene and Beyond," Technion, Haifa, Israel, 7/6/15.

T. F. Heinz, "Optical Properties of Atomically Thin Semiconductor Layers and Heterostructures," Flatlands 2015, Ramat Gan, Israel, 7/7 – 7/10/15.

Y. You and T. F. Heinz, "Excitonic Effects in Atomically Thin Semiconductors," Physics and Device Applications of Two-Dimensional Materials, Nanjing, China, 7/13 – 7/15/15.

T. F. Heinz, "Optical Properties of Atomically Thin Semiconductor Layers and Heterostructures," Fundamental Optical Properties of Semiconductors, Breckenridge, CO, 8/3 – 8/7/15.

T. F. Heinz, "Many-Body Interactions in 2D Materials Probed by Optical Spectroscopy," Moore Foundation Symposium, Sausalito, CA 8/4 – 8/7/15.

T. F. Heinz, "Addressing and Tuning the Valley Degree of Freedom in Atomically Thin Semiconductors," Spintech 8, Basel, Switzerland, 8/10-8/12/15.

T. F. Heinz, *Plenary Talk:* "Two-Dimensional Semiconductors," Pioneers Symposium on Photonic and Electronic Nanostructures, Seoul, Korea, 8/13-8/14/15.

T. F. Heinz, "Probing Two-Dimensional Materials Optically: Graphene and Beyond," Center for Integrated Nanotechnologies CINT Users Meeting, Santa Fe, NM, 9/21-9/22/15.

T. F. Heinz, "Atomically Thin Two-Dimensional Materials - Graphene and Beyond," Material Science and Engineering Colloquium, Stanford University, 10/2/15.

T. F. Heinz, "Optical Properties of 2D Semiconductors and Heterostructures," Laser Science/Frontiers in Optics Meeting, San Jose, CA, 10/19-10/22/15.

T. F. Heinz, "Two-Dimensional Materials: Graphene and Beyond," National Symposium of the American Vacuum Society, San Jose, CA, 10/19-10/23/15.

T. F. Heinz, "Novel Properties of 2D Transition Metal Dichalcogenide Crystals," Graphene Canada 2015, Montreal, Canada, 10/14-10/16/15.

T. F. Heinz, "Optical Properties of Atomically Thin Semiconductors Layers and Heterostructures," The Conference of Advances and Applications in Carbon Related Nanomaterials, Benasque, Spain, 12/7-12/11/15.

T. F. Heinz, "Interactions in Atomically Thin Semiconductors and Heterostructures," La Jolla Workshop on Big Ideas in Quantum Materials, San Diego, CA, 12/14-12/17/15.

T. F. Heinz, "Excitonic Effects in 2D Semiconductor Layers," 43rd Physics and Chemistry of Surfaces and Interfaces Conference - PCSI 43, Palm Springs, CA, 1/17-1/21/16.

T. F. Heinz, "Two-dimensional materials - Graphene and Beyond," Physics Colloquium, Harvard University, Cambridge, MA, 4/11/16.

T. F. Heinz, *Plenary Talk:* "Atomically Thin Semiconductors and Heterostructures," Graphene Week Conference 2016, Warsaw, Poland, 6/13-6/17/16.

T. F. Heinz, “Electronic Excitations and Dynamics in 2D Semiconductors,” Ultrafast Dynamics at the Nanoscale, Okinawa, Japan, 7/13-7/16/16.

T. F. Heinz, *Plenary Talk:* “Seeing electrons in 2D - light/matter interactions in atomically thin semiconductors” International Conference on the Physics of Semiconductors ICPS 2016, Beijing, China, 7/31-8/5/16.

T. F. Heinz, “Controlling Excitons in 2D Semiconductors,” 2nd EPiQS Investigator Symposium of the Moore Foundation, Aptos, CA, 8/2-8/5/16.

T. F. Heinz, *Plenary Talk:* “Two-Dimensional Semiconductors: The Counterpart to Graphene,” Sixteen International Conference on the Science and Application of Nanotubes NT16, Vienna, Austria, 8/7-8/13/16.

T. F. Heinz, “Seeing Electrons in 2D - Light/matter Interactions in Atomically Thin Semiconductors,” Workshop on Nanoscale Matter, Venice, Italy, 9/18-9/23/16.

T. F. Heinz, “Atomically Thin Semiconductors and Heterostructures,” EU Graphene Flagship – US NSF Workshop - 2D Materials, Heterostructures and Devices, Manchester, UK, 10/10-10/13/17.

T. F. Heinz, “Controlling Excitons in 2D Materials,” International Winterschool on the Electronic Properties of Novel Materials, Kirchberg, Austria, 3/4/ - 3/11/17.

T. F. Heinz, *Plenary Talk:* “Seeing Electrons in 2D – Light/Matter Interactions in Atomically Thin Semiconductors,” Graphene 2017, Barcelona, Spain, 3/28 – 3/31/17.

T. F. Heinz, “Optical Properties of Atomically Thin Two-dimensional Materials,” Conference on Lasers and Electro-Optics CLEO 2017, San Jose, CA, 5/14 – 5/19/17.

T. F. Heinz, “Light-matter interactions in 2D semiconductors,” Eighth International Conference on Physics of Light-Matter Coupling in Nanostructures, Wuerzburg, Germany, 7/9 – 7/14/17.

T. F. Heinz, “Controlling Excitons in 2D Materials,” Nanophotonics of 2D Materials N2D 2017, San Sebastián, Spain, 7/31 – 8/3/17.

T. F. Heinz, “Controlling Excitons and the Valley Degree of Freedom in 2D semiconductors,” Valleytronics Workshop, Cambridge, MA, 8/22-8/23/17.

T. F. Heinz, “Controlling Excitons and the Valley Degree of Freedom in 2D semiconductors,” Fundamental Optical Processes in Semiconductors FOPS 2017, Stevenson, WA, 8/27 – 9/1/17.

T. F. Heinz, “Controlling the Valley Degree of Freedom in 2D Transition Metal Dichalcogenides,” International Symposium of the American Vacuum Society, Tampa, FL, 10/29 – 11/3/17.

T. F. Heinz, “Seeing Electronics in 2D: Optical Spectroscopy of Atomically Thin Materials,” CUI Symposium in Honour of A. Millis, Hamburg, Germany, 11/9/17.

T. F. Heinz, “Many-Body Effects in Atomically Thin Materials,” MRS Fall Meeting, Boston, MA, 11/27- 12/1/17.

T. F. Heinz, "Controlling Excitons and Many-Body Interactions in 2D Semiconductors," Physics of Quantum Electronics PQE-2018 Conference, Snowbird, UT, 1/7 – 1/12/18.

T. F. Heinz, "Dynamics of Excitons and the Valley Degree of Freedom in 2D Semiconductors," Gordon Research Conference on Ultrafast Dynamics in Cooperative Systems, Galveston, TX, 2/4 -2/9/18.

T. F. Heinz, *Keynote Address:* "Tuning both the optical and electronic properties of atomically thin materials," Graphene for US, New York, NY, 2/22-2/23/18.

T. F. Heinz, "Seeing and Controlling Dark and Bright excitons in 2D Materials," Excited State Processes in Electronic and Bio Nanomaterials Conference, Santa Fe, NM, 6/4 – 6/7/18.

T. F. Heinz, "Probing and controlling excitations in transition metal dichalcogenides with magnetic fields," 23rd International Conference on High Magnetic Fields in Semiconductor Physics (HMF-23), Toulouse, France 7/22 – 7/27/18.

T. F. Heinz, *Plenary Talk*: "Probing and controlling excitons in 2D semiconductors," International Conference on Superlattices, Nanostructures and Nanodevices, Madrid, Spain, 7/23 – 7/27/18.

T. F. Heinz, "New Quantum Effects in 2D Materials," DoD Planning Meeting on Materials for Quantum Applications, Arlington, VA, 8/14 – 8/15/18.

T. F. Heinz, "Seeing electrons in two dimensions," Ultrafast Optics Symposium, Vienna, Austria, 9/21/18.

T. F. Heinz, *Plenary Talk:* "Optical properties of 2D materials and heterostructures," IEEE 13th Nanotechnology Materials and Devices Conference (NMDC 2018), Portland, OR, 10/14 – 10/17/18.

T. F. Heinz, "Excitons in 2D Materials," International Workshop on Spin and Valley Effects in 2D Materials, Daejon, South Korea, 5/20-5/24/19.

T. F. Heinz, *Plenary Talk*: "Seeing and Controlling Excitons in 2D Materials," Twentieth International Conference on the Science and Applications of Carbon Nanotubes and Low Dimensional Materials NT19, Wuerzburg, Germany, 7/21-7/26/19.

T. F. Heinz, "Optical Properties of 2D Semiconductors and Heterostructures," Winter School on 2D Materials, Rehovot, Israel, 1/14-1/17/19.

E. Y. Ma and T. F. Heinz, "Excitons and Charge Transfer in Atomically Thin 2D Heterostructures," OSA Advanced Photonics Congress, Burlingame, CA, 7/29-8/1/19.

T. F. Heinz, "Ultrafast Electron Dynamics in 2D Materials and Heterostructures," Femto14 – Femtochemistry Conference – Dynamics of Complexity in Chemistry, Biology, and Physics, Shanghai, China, 7/28-8/2/19.

T. F. Heinz, "Quantum Emitters in 2D Semiconductors," NSF Workshop on Enabling Quantum Leap, Philadelphia, PA, 9/20/19.

T. F. Heinz, *Plenary Talk*: "Seeing and Controlling Excitons in 2D Materials," Center for Integrated Nanotechnologies Annual Meeting, Santa Fe, NM, 9/22-9/24/19.

T. F. Heinz, "Controlling Excitons in 2D Materials," ALS Users Meeting Symposium on Layered Materials, Berkeley, CA, 10/2-10/3/19.

T. F. Heinz, *Plenary Talk:* "Electronic and Optical Properties of Atomically Thin Semiconductors," International Conference on Two-Dimensional Layered Materials ICON-2DMAT, Suzhou, China, 10/21 – 10/24/19.

T. F. Heinz, "Electron Correlation Effects in 2D Materials," Symposium on Non-Equilibrium Quantum Phenomena, Flatiron Institute, New York, NY, 11/19-11/20/19.

T. F. Heinz, Materials Research Society Fall Meeting, "Probing and Controlling Excitons in 2D Semiconductors," Boston, MA, 12/2 – 12/6/19.

T. F. Heinz, *Plenary Talk:* "Electronic and Optical Properties of Atomically Thin Semiconductors," Eleventh International Conference on Advanced Materials and Device ICAMD, Jeju, South Korea, 12/10 – 12/13/19.

T. F. Heinz, "Probing Excitons in 2D Materials in Momentum Space," APS March Meeting, 3/15-3/19/21.

T. F. Heinz, "Probing Correlated Excited Electronic States in Moiré Heterostructures," EPiQS Syposium, Moore Foundation, 8/9 – 8/12/21.

T. F. Heinz, "Following Catalytic Reaction of the Ultrafast Time Scale Using Free Electron Lasers," SUNCAT Sumer Institute, 8/16 – 8/19/21.

T. F. Heinz, "Probing Excitons in 2D Materials in Momentum Space," Optics of Excitons in Confined Systems OECS 17, (online) Dortmund, Germany, 8/30 -9/3/2.

T. F. Heinz, "Probing Excitons in 2D Materials in Momentum Space," International Workshop on Emergent Relativistic Effects in Condensed Matter, (online) Regensburg, Germany, 9/22 – 9/24/21.

T. F. Heinz, "Controlling Excitons in 2D Materials and their Heterostructures," NanoIsrael 2021, (online) Jerusalem, Israel, 10/4 – 10/6/21.

T. F. Heinz, "Probing and Controlling Excitons in 2D Materials," Welch Prize Lecture, American Vacuum Society International Symposium - AVS67, 10/25 – 10/28/21.

T. F. Heinz, "Seeing Electrons in 2D," Douglas Osheroff Lectureship, Universidad Autónoma de Ciudad Juárez, (online) Mexico, 11/17/21.

T. F. Heinz, "Probing Excitons in 2D Semiconductors and Heterostructures in Momentum Space," MRS Fall Meeting, Boston, MA 12/6 – 12/8/21.

T. F. Heinz, "2D Semiconductors as Highly Tunable Optoelectronic Building Blocks," MRS Fall Meeting, Boston, MA, 12/6 – 12/8/21.

T. F. Heinz, "Probing Excitons in 2D Semiconductors and Heterostructures in Momentum Space," Berkeley Excited States Conference – BESC 2022, 1/13-1/14/22.

T. F. Heinz, "Probing electrons and electron dynamics in 2D materials and heterostructures," Conference on Ultrafast Spin Dynamics, (online) Berlin, Germany, 3/9 – 3/11/22.

T. F. Heinz, "Advances in Optical Spectroscopy of Nanomaterials" (tutorial), APS March Meeting, Chicago, IL, 3/14-3/18/22.

T. F. Heinz, "Ultrafast and Strong-Field Effects in 2D Materials," The Frontiers of Attosecond and Ultrafast X-ray Science, Erice, Italy (online), 3/21-3/25/22.

T. F. Heinz, "Schawlow Prize Lecture: Probing and Controlling Excitons in 2D Semiconductors," Frontiers in Optics, Rochester, NY, 10/9 – 10/12/22.

T. F. Heinz, "Properties and Control of Excitons in 2D Semiconductor Heterostructures," MRS Fall Meeting, Boston, MA, 11/27 – 12/2/22.

T. F. Heinz, Joint Quantum Institute, "Excited States in 2D Semiconductors and Heterostructures," University of Maryland - NIST, 02/13/23.

T. F. Heinz, "Probing Excitons in Momentum Space," Massachusetts Institute of Technology, Cambridge, MA, 02/20/23.

T. F. Heinz, *Crawford Memorial Lecture:* "Seeing Electrons in Two Dimensions," University of Pittsburgh, 02/21/23.

T. F. Heinz, *Pittsburgh Quantum Institute Distinguished Lecture:* "Optically Excited States in 2D Semiconductors and Heterostructures," University of Pittsburgh, 02/22/23.

T. F. Heinz, "Excitons in 2D Semiconductors and Heterostructures: A Momentum-Space View," International Winter School of Electronic Properties of Novel Materials, Kirchberg, Austria, 03/18-23/23.

T. F. Heinz, "Optically Excited States and their Dynamics in Atomically Thin Semiconductor heterostructures," MRS Spring Meeting, San Francisco, CA, 04/18-21/23.

T. F. Heinz, "Seeing Electrons in Two Dimensions," Dept. of Physics and Astronomy, Texas Tech University, Lubbock, TX, 04/19/23.

T. F. Heinz, *Bucy Lecture* "Capturing Motion in Real Time down to Atoms and Electrons," Dept. of Physics and Astronomy, Texas Tech University, Lubbock, TX, 04/19/23.

T. F. Heinz, "Excited States in 2D Semiconductors and Heterostructures," Department Chemistry, University of Chicago, 5/8/23.

T. F. Heinz, "Excitons in 2D Semiconductors and Heterostructures," Trends in Quantum Matter, Notre Dame University, South Bend, IN, 05/18 – 19/23.

T. F. Heinz, "Excited states and their dynamics in 2D materials and heterostructures," Workshop on Excited-State Dynamics, Simons Foundation, New York, NY, 5/24-25/23.

T. F. Heinz, *Plenary Talk:* "Excited States in 2D Transition Metal Dichalcogenides and their Heterostructures," 2D Transition Metal Dichalcogenides 2023, Cambridge, UK, 6/26-29/23.

T. F. Heinz, Thouless Institute for Quantum Matter Workshop, "Light-matter interactions in 2D materials," University of Washington, Seattle, WA, 8/5 -7/23.

T. F. Heinz, “Probing excitons in 2D semiconductor monolayers and heterostructures,” Symposium on Forty Years of Semiconductor Nanocrystals, Columbia University, New York, NY, 8/10-11/23.

T. F. Heinz, “Excited States in 2D Semiconductors and Heterostructures,” American Chemical Society Fall 2023 Meeting, San Francisco, CA, 8/12-17/23.

T. F. Heinz, “Excited states in 2D semiconductors and heterostructures probed by optical spectroscopy and momentum space imaging,” Rice University, Houston, TX, 8/24/23.

T. F. Heinz, *Condon Lecture:* “Excited states in 2D materials and heterostructures,” University of Colorado, Boulder, 10/20/23.

T. F. Heinz, “Imaging excitons in 2D semiconductor monolayers and heterostructures in momentum space,” Gordon Research Conference on Two Dimensional Electronics Beyond Graphene, Manchester, NH, 6/16 – 6/21/24.

T. F. Heinz, *Plenary Talk:“*Light-matter interactions in 2D semiconductors and their heterostructures,” CLEO-PR, Incheon, South Korea, 8/4 – 8/9/24.

T. F. Heinz, “Seeing electrons in two dimensions: Optical spectroscopy of 2D materials,” Physics Colloquium, Ohio State University, 8/27/24.

T. F. Heinz, “Creating and probing localized excitons in 2D semiconductors,” MRS Spring Meeting, Seattle, WA, 4/4- 4/11/25

T. F. Heinz, *Plenary Talk:* “Controlling and probing excitons in 2D materials,” IEEE-Nano 2025: International Conference on Nanotechnology, Arlington, VA, 7/12 – 7/16/25.

T. F. Heinz, *Physical Chemistry Prize Session,* “Dynamics of excitons in 2D materials,” ACS Fall 2025 National Meeting, 8/17-8/21/25.

T. F. Heinz, “Imaging excitons in momentum space,” At the Frontier of Light-Matter Interaction, Flatiron Institute, New York, NY, 9/24-9/26/25.

T. F. Heinz, *Plenary Talk* “Engineering localized excitons in 2D materials,” Workshop on Creating Novel States of Matter via Enhanced Light-Matter Interactions, Argonne National Laboratory, 10/20-/21/25.

T. F. Heinz, “Creating Localized Excitons in 2D Semiconductors,” APS Global Physics Summit, Denver, CO, 3/15-3/20/26.

T. F. Heinz, “Optics of 2D materials,” Stanford University Photonics Retreat, Pacific Grove, CA, 4/10 – 4/12/26.

T. F. Heinz, “Two Dimensional Electronics Beyond Graphene,” Gordon Research Conference, Manchester, NH, 6/21-6/26/26.

T. F. Heinz, “Creating and Probing Localized Excitons in 2D Materials,” Workshop on Light-Matter Interactions in 2D Materials, Stanford, CA, 6/29-6/29/26.

PATENTS FOR TONY F. HEINZ

1. US Patent 5,294,289: T. F. Heinz, G. S. Selwyn, S. Singh, and J. A. Spinetti, Jr., "Detection of interfaces with atomic resolution during material processing by optical second harmonic generation" (1994).

2. US Patent 5,338,390: S. G. Barbee, T. F. Heinz, L. Li, and E. H. Ratzlaff, "Contactless real-time in-situ monitoring of a chemical etching process" (1994).

3. US Patent 5,456,788: S. G. Barbee, M. Datta, T. F. Heinz, L. Li, E. H. Ratzlaff, and R. V. Shenoy, "Method and apparatus for contactless real-time in-situ monitoring of a chemical etching process" (1995).

4. US Patent 5,445,705: S. G. Barbee, M. Datta, T. F. Heinz, L. Li, E. H. Ratzlaff, and R. V. Shenoy, "Method and apparatus for contactless real-time in-situ monitoring of a chemical etching process" (1995).

5. US Patent 5,451,289: S. G. Barbee, T. F. Heinz, L. Li, and E. H. Ratzlaff, "Fixture for in-situ noncontact monitoring of wet chemical etching with passive wafer restraint" (1995).

6. US Patent 5,392,124: S. G. Barbee, T. F. Heinz, U. Hofer, L. Li, and V. J. Silvestri, "Method and apparatus for real-time, in-situ endpoint detection and closed loop etch process control" (1995).

7. US Patent 5,386,121: S. G. Barbee, T. F. Heinz, L. Li, ad V. J. Silvestri, "In situ, non-destructive CVD surface monitor" (1995).

8. US Patent 5,381,234: S. G. Barbee, T. F. Heinz, R. J. Lebel, L. Li, and V .J. Silvestri, "Method and apparatus for real-time film surface detection for large area wafers" (1995).

9. US Patent 5,559,428: L. Li, S. G. Barbee, A. Halperin, and T. F. Heinz, "In-situ monitoring of the change in thickness of films" (1996).

10. US Patent 5,582,746: S. G. Barbee, T. F. Heinz, Y. Hsiao, L. Li, E. H. Ratzlaff, and J. W. Wong, "Real time measurement of etch rate during a chemical etching process" (1996).

11. US Patent 5,573,623: S. G. Barbee, T. F. Heinz, L. Li, and E. H. Ratzlaff. "Apparatus for contactless real-time in-situ monitoring of a chemical etching process" (1996).

12. US Patent 5,573,624: S. G. Barbee, T. F. Heinz, Y. Hsiao, L. Li, E. H. Ratzlaff, and J. W. Wong, "Chemical etch monitor for measuring film etching uniformity during a chemical etching process" (1996).

13. US Patent 5,489,361: S. G. Barbee, T. F. Heinz, Y. Hsiao, L. Li, E. H. Ratzlaff, and J. W. Wong "Measuring film etching uniformity during a chemical etching process" (1996).

14. US Patent 5,516,399: M. J. Balconi-Lamica, S. G. Barbee, T. F. Heinz, Y. Hsiao, L. Li, and E. H. Ratzlaff, "Contactless real-time in-situ monitoring of a chemical etching" (1996).

15. US Patent 5,500,073: S. G. Barbee, T. F. Heinz, Y. Hsiao, L. Li, E. H. Ratzlaff, and J. W. Wong, "Real time measurement of etch rate during a chemical etching process: (1996).

16. US Patent 5,480,511: S. G. Barbee, T. F. Heinz, L. Li, and E. H. Ratzlaff, “Method for contactless real-time in-situ monitoring of a chemical etching process” (1996).

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18. US Patent 5,660,672: L. Li, S. G. Barbee, A. Halperin, and T. F. Heinz, “In-situ monitoring of conductive films on semiconductor wafers” (1997).

19. US Patent: 5,788,801: S.G. Barbee, T. F. Heinz, Y. Hsiao, L Li, E. H. Ratzlaff, and J. W. Wong, “Real time measurement of etch rate during a chemical etching process” (1998).

20. US Patent 6,072,313: L. Li, Steven S. G. Barbee, A. Halperin, and T. F. Heinz, “In-situ monitoring and control of conductive films by detecting changes in induced eddy currents” (2000).

RESEARCH SUMMARY FOR TONY HEINZ

(This summary of research accomplishments references publications in the appended list.)

Surface nonlinear optics

Already a graduate student in Y. R. Shen's group, Heinz made major contributions to the development of second-harmonic and sum-frequency as a probe surfaces and interfaces [2]. The technique relies of the suppression of second-order nonlinear optical processes in the bulk of centrosymmetric media to obtain monolayer optical sensitivity to symmetry-lowering surfaces and interfaces. In addition to the development of the experimental methods for spectroscopic [6] and orientational analysis of adsorbates through the tensor properties of the surface nonlinear susceptibility [10]. Heinz's derivation of radiation from an interfacial nonlinear response remains an essential building block of this important technique [10,50,66].

Spectroscopy development and nonlinear optical foundations:

Important subsequent developments include the methodology for measurement of the absolute SHG phase [27] to infer polar ordering, analysis of surface diffusion [47] by SHG diffraction [36], and probing of ultrafast molecular dynamics by optical pump / nonlinear probe methods [91,93]. The analysis of surface crystallographic orientation [14] and atomic reconstruction [20] of crystal materials further advanced the method, including it important recent extension to 2D crystals [208]. His rigorous treatment of SHG from small particles [87,116] has been widely recognized and applied to probe the surfaces of colloids and aerosols. Recent research has extended surface SHG even to the regime of high harmonics in the non-perturbative, strong-field regime [258, 317]. Applications of this and related methods also led many issued US patents for in-situ semiconductor process control (See patent list.aboe)

Applications of the approach:

Through the application of this method Heinz has addressed basic issues in surface science, such as optical probing of silicon reconstruction and its dynamics [20,67], of the kinetics elementary surface reactions, notably hydrogen on clean silicon surfaces [46,53], and of adsorbate diffusion [47]. The method also identified new interface electronic states, such as those in the model epitaxial CaF_2/Si(111) interface [35]. The approach has become the standard methods by which surfaces and interfaces can be probed with atomic level sensitivity using a fully non-contact optical probe. Also sparked by the early work was the development of SHG microscopy for biological imaging. This method complements 2-photon fluorescence by its distinct contrast, i.e., to polar ordering, and its broad applicability to systems with the addition of chromophores. Recently an FDA diagnostic instrument has been authorized to identify skin abnormalities.

Ultrafast surface dynamics

At IBM, Heinz first demonstrated the possibility of inducing and tracking molecular motion at surfaces on the femtosecond time scale using ultrafast lasers [44]. These investigations combined the capabilities of ultrafast lasers and controlled ultrahigh vacuum conditions with well-defined, ordered molecular adsorbates on clean metal surfaces to address long-standing fundamental issues on the role of non-adiabatic adsorbate coupling. In particular, the research addressed the question of whether adsorbate/substrate energy exchange when a molecular adsorbs or desorbs occurs through coupling to the phonons in the substrate or through coupling to electron-hole pair excitations. By exciting the surface with a femtosecond pulse, it was possible to produce high electron temperatures, but low phonon temperatures in the metal. This permitted a direct

assessment of the role of electronic coupling to adsorbate motion. A further important advance was the introduction of two-pulse ultrafast correlation techniques to obtain direct time-domain information about the dynamics [48].

These studies were extended to examine dissociation and competitive chemical processes [75], probe isotope effects [111], and even to obtain ultrafast dynamical information on a site-specific bases by final state detection with scanning tunneling microscopy [118]. Heinz and colleagues also developed theoretical models of non-adiabatic coupling to model the observed dynamics [51,54]. These pioneering studies helped to create an important new line of research using the unique capabilities afforded by modelocked lasers to reach down to the fundamental time scales of chemical transformations at surfaces [60]. The power of ultrafast lasers was, of course, widely recognized in the chemistry community in the context of isolated gas and solution phase molecules, but had not previously been extended to address model problems in surface dynamics, despite their fundamental importance in heterogeneous catalysis. Recently, Heinz has returned to address these questions with a similar overall experimental methodology, but now based on femtosecond x-ray pulses from free electron lasers [302,316,318]. The use of x-rays, with access to core-level atomic signatures, allows this line of research to expand to systems with greater chemical complexity relevant to key reactions in heterogeneous catalysis. These accomplishments were recognized by the 2025 Ahmed Zewail Prize for ultrafast science of the American Chemical Society.

THz time-domain spectroscopy

Terahertz time-domain spectroscopy provides a very sensitive means for spectroscopy in the otherwise difficult to access far-infrared spectrum. In probing many systems, it can be considered as offering a non-contact signature of electrical conductivity. The method also provides access to low-frequency vibrations in molecules and to phonons and other collective modes in solids. These capabilities are of great value for the study of many different types of physical systems - from molecules to solids to nanoscale materials and thin films. With his background in nonlinear optics, Heinz made crucial advances to this methodology through the use of non-resonant second-order nonlinear materials in the place of the then-usual photoconductive emitters and detectors. At the same time, Heinz applied these capabilities in noteworthy studies of various materials, particularly nanoscale systems and 2D layers.

Advances in measurement technique:

More specifically, Heinz demonstrated the first THz time-domain spectroscopy system based entirely on the non-resonant nonlinear processes of optical rectification and electro-optic sampling, without any photoconductive elements [71]. This work extended the bandwidth of the approach and elucidated the requirements for nonlinear crystals to achieve a wide spectral range. This work has been highly cited and opened the door to further increases in bandwidth and to the use of the technique by scientists not wishing to develop specialized photoconductors. Further advances by Heinz's group built on this work, notably extending the spectral range to > 30 THz in the mid-infrared using thin-film nonlinear materials for electro-optic sampling [106]. Also of note were the demonstration of single-shot THz waveform capture [94] using the multichannel detection possibilities of electro-optic sampling, spatial imaging techniques and the use of cw sources [89], advances in optical pump/THz probe techniques [182], and THz emission spectroscopy to probe interfaces [283].

Spectroscopic applications:

With these spectroscopic tools at hand, the Heinz group was able to obtain new insight into charge transport in photoexcited materials that were difficult or impossible to explore in other ways. Probing with THz pulses permitted the complex frequency-depending conductivity to be extracted from materials without the need for electrical contacts. The approach was applied to diverse systems, including to the determination of the scattering rate of solvated electrons in liquids [119] and the characterization of polaronic effects in the charge transport of model insulators [112,115]. With regard to nanoscale materials, the method provided a quantitative determination of magnitude and size scaling of the polarizability of photogenerated charges in semiconductors quantum dots [137]. The method also revealed a counter-intuitive result that photoexcitation of graphene typically led to a decreased conductivity, a finding revealed to result from an enhanced carrier scattering rate, partially offset by an increased Drude weight [201]. Quite recently, the related approach of THz emission spectroscopy with electro-optic sampling was applied to a 2D heterostructure between two semiconductor monolayers [283]. The method provided a quantitative, real-time measurement of the ultrafast current flow between the two layers of material separated by less than a nanometer. This permitted tracking of the dynamics of relaxation as electron occupied their lowest state in one material and the holes in the other, reflecting the system's type II band alignment.

Probing 1D nanomaterials

Heinz has made major contributions to the spectroscopy of nanoscale materials, including quantum dots (0D), carbon nanotubes (1D), and layers of atomically thin two-dimensional (2D) materials.

Spectroscopy of individual nanotubes:

Single-walled carbon nanotubes are distinguished by their chiral index, which defines the precise way in which a graphene sheet can be wrapped into a nanotube. The chiral index defines the precise electronic structure of the nanotube, including its metallic or semiconducting character and band gap. In understanding the properties of nanotubes, optical characterization of the electronic transitions for specific structures has played a central role. In particular, because nanotube ensembles typically include various different chiral indices, there is great value in methods that can probe individual nanotubes. While photoluminescence can reach this goal for semiconducting nanotubes (with high quantum yield), the family of metallic nanotubes could not be seen. Heinz and collaborators introduced a new approach [125,133], namely, elastic light scattering in a Rayleigh scattering measurement. Using laser generated supercontinuum spectra, this method provides precise information on electronic transitions of all types of nanotubes at the individual tube level. This method also allowed the precise study of nanotube-nanotube interactions [132].

Using enriched ensemble samples, where the different tube could be distinguished spectroscopically, Heinz and collaborators were able to elucidate key fundamental properties and processes of photoexcited nanotubes. In addition to determining radiative lifetimes [117] by time-resolved photoluminescence measurements, the work of the Heinz group first demonstrated many-body interactions in the excited state, notably, the role of Auger recombination processes [122, 135].

Nature of optically excited states in nanotubes:

Perhaps most notably, research led by the Heinz group completely changes the understanding of the nature of excited states in carbon nanotubes [126]. Until this work, the sharp peaks in the optical spectra of nanotubes had been ascribed to van Hove singularities in the joint density of states, a characteristic of bands in 1-D systems. In fact, the sharp features are the result of the formation of tightly bound excitons. This new perspective was shown through two-photon photoluminescence. This allowed 2*p* excitons to be observed, contrasting to the strong one-photon transition to the 1*s* state. The experiment thus revealed the excitonic nature of the states, as well as their high binding energy. After this work, the entire description of optically excited states in these model 1D nanomaterials.

Probing 2D nanomaterials

Heinz is broadly recognized for his key role in the development of the field of atomically thin 2D materials through the use of optical spectroscopy. Indeed, Heinz's work was largely responsible for sparking the huge international effort in 2D semiconductors, thus transforming the field of "graphene" into the current "2D materials."

Graphene:

In the graphene, the 2D material that launched the field, Heinz established many of its key optical properties and light-matter interactions. Research led to a better understanding of excited states, but also through Raman spectroscopy of widely used characterization methods for identifying stacking order in few-layer samples.

Light-matter interactions in graphene and few-layer graphene: Early on, together with the Manchester group, Heinz experimentally validated the predicted optical absorption defined only by fundamental constants, namely, $\pi\alpha$ = 2.3%, over an appropriate spectral range [144]. The limitations of this relationship at higher photon energies where the band structure deviated from linearity were also demonstrated in a study of the resulting saddle-point excitons [178].

Heinz's research extended to understanding the excited-state properties and electronic structure of few-layer graphene, including an elegant analysis of the evolution of the band structure and optical absorption up to the bulk limit [172]. Another research highlight was the demonstration that bilayer graphene could be tuned from a semi-metallic state to a narrow direct gap material through the symmetry lowering application of a perpendicular electric field. Within the trilayer system, Heinz identified the presence of two possible stacking orders (Bernal) and rhombohedral and developed a Raman spectroscopy diagnostic and imaging method that has been widely applied in the field [177]. More fundamentally, the different electronic structure and symmetry of these two materials was elucidated through spectroscopy studies under applied electric fields [167, 184]. These works remain central to ongoing developments of flat-band and correlated electron physics in these systems.

Ultrafast dynamics and nonequilibrium states in graphene: Heinz's work played a central role in understanding the dynamics of electrons and phonons in graphene through a variety of pump-probe measurements. In particular, Heinz's research revealed the unusual behavior induced by optical pumping: The optical absorption could be made either to increase (through increased free-carrier absorption) or decrease absorption though the increased Pauli blocking [198]. The two distinct processes were identified by their different fluence dependence and dynamics. These materials have been used as saturable absorbers to stabilize modelocked lasers. Other notable results include the demonstration of thermal radiation from the electronic system at temperatures to many thousands of Kelvins in a transient nonequilibrium regime created by ultrafast pumping

[173]. These results provided key information about rates of electron thermalization and electron phonon coupling, as revealed through direct time-domain two-pulse correlation measurements. They underpinned more device-oriented research on light emission from graphene induced by electrical currents [241, 276].

2D semiconductor monolayers:

Among Heinz's research accomplishments, perhaps no one result is as widely recognized as his group's identification of transition metal dichalcogenides (TMDCs) as direct-gap semiconductors at the monolayer level [176]. While the bulk material (and layers of thickness greater than the monolayer) exhibited indirect-gap behavior and low light emission efficiency, the monolayer to be an optically bright material with a direct bandgap at the corner of its Brillouin zone. Thus, these materials (including MoS_2, $MoSe_2$, $MoTe_2$, WS_2, and WSe_2) we recognized as closely analogous to graphene, but with broken in-plane inversion symmetry and bandgaps in the important 1.5 – 2.0 eV range. The materials were also shown to be air stable and readily produced by exfoliation in controlled layer thickness. These materials effectively created the current field of 2D materials from what was initially the initial research area of graphene. In addition to the optical properties of these materials, they could be immediately used as field-effect transistors exhibiting high on-off ratios, unlike what is achievable in the semi-metallic graphene system. The broad impact and importance of this initial paper can be gauged by the >17,800 citation (google scholar) it has received to date. A related paper in which Raman spectroscopy [168] was developed to readily assess layer thickness was also a key advance for the field, with > 5,500 citations to date.

After this initial breakthrough, the Heinz group's work helped to define other distinctive and important properties of this class of materials. Three key aspects should be mentioned.

Valley-degree of freedom: These systems have two degenerate, but quantum mechanically distinguishable sets of bands related by inversion symmetry. In particular, the conduction band minima and valence band maxima lie at the K and -K points in the Brillouin zone. Using optical spectroscopy, the Heinz group demonstrated that these distinct, but degenerate valleys could be accessed by the use of the helicity of light, with each circular polarization producing only excitation in one of the two valleys [192]. This result launched the field of valley physics in these materials, which is also correlated to control of with carrier spin through the so-called spin-valley locking effect [220]. Among other important related advances in this field, the Heinz group used this optical selection rule to demonstrate and quantify the spin/valley-Hall effect in which carriers in different valleys experience different transverse forces when drifting under an electric field. This was revealed by spatial mapping carrier spin/valley states in a field-effect transistor by Kerr rotation measurements [284]. Also, in a significant development towards all optical control of valley degree of freedom, the optical Stark effect, which is valley specific when applied with circularly polarized light, was shown to allow coherent valley pseudospin manipulation between the two valleys [256]. Recent collaborative research has also aimed to overcome intervalley relaxation processes by increasing radiative coupling through the integration of 2D materials with silicon optical meta-surfaces providing significant enhancements through the Purcell effect [319].

Excitonic properties: The second area that defined key optical properties of these novel materials concerned the excitonic character of the optically excited states. The key parameter in determining the degree to which optically excited states in solids behave like uncorrelated electrons and hole or, alternatively, like bound electron-hole pairs in excitons is generally the degree of screening provided by the other electrons in material. For the case of monolayer semiconductors, it was found that excitonic effects dominate to a degree that is not found in

typical bulk semiconductors, where excitonic effects are relatively weak and typically only crucial at low temperatures. In these 2D semiconductors, the Heinz group demonstrated that through exciton Rydberg spectroscopy [227] that the binding energies were in the range of several hundred meV and, correspondingly dominated the optical properties even at room temperature. The Rydberg exciton spectra also revealed the spatially non-local screening associated with the 2D nature of the materials: Screening at long distances, where field lines left the material, were much weaker than those at short distances, yielding high non-hydrogenic spectra and a signature of nanoscale electron-hole interactions. The strong excitonic interactions are intrinsic to these materials and present under almost all conditions. However, at very high exciton density, signatures of a Mott transition to a free-carrier regime with population inversion were idenfied[239]. Below this density regime, the Heinz group also first characterized the excitonic Auger effect by which excitons undergo nonradiative decay [228].

The Heinz group extended this understanding to identify important higher-order excitonic states, such as charged excitons (or trions) in doped materials [199], as well the molecular biexciton state [235] and even the five-body charged biexciton [270]. In the community, the spectroscopic signatures of the trions are widely relied upon assessing doping in these materials and recently in their (moiré) heterostructures, while the biexcitons are viewed as potential sources of entangled photons. Another important advance reached through experiments that clarified the role and energetics of spin-allowed and spin-forbidden excitons [262] and the underlying spin-split band structure and exciton exchange interactions. The exciton spin fine structure leads to very different low temperature optical behavior among the different TMDC materials, as had been identified earlier [248]. A basic measurement of the dielectric function / optical conductivity of this class of materials has also been a building block for the field, with the three last named papers having been cited around 3000 times to date.

Interactions with the external environment: Lastly the optical and electronic properties of these materials are recognized by virtue of their atomic level thickness as being sensitivity as being both controllable by the external environment and coupled to ways that are familiar in molecular systems, but generally note relevant in solids. An example of the former is the ability to apply very large strain fields to strongly tune the materials' band gap and optical properties [272,288]. An important example of the latter goes under the heading of Coulomb engineering, the coupling of the electronic states and excitations in the 2D semiconductors to their external dielectric environment. This is an intrinsic feature of the limit atomically thin semiconductors. The magnitude and significance of this effect was revealed in a very direct fashion by experiments in which 2D semiconductors were probed optically in combination with different external media by Heinz and collaborators [261,281], as well as in photoemission experiments examining more fully band renormalization across momentum space [286]. This fundamental aspect of 2D semiconductors cannot be included in the design of devices and has already been explicitly shown to allow the creation of a diode using a homogeneous semiconductor in a spatially split dielectric environment.

2D heterostructures:

The combination of the attractive inherent properties of monolayer materials and the flexibility afforded by the ability to stack 2D materials together in a nearly arbitrary fashion has created an enormous and vital field of science and technology, one being pursued across the world and extending across different scientific disciplines and aimed at widely varying applications. The fundamental studies of key building blocks described above, and the associated methods of their optical characterization, has played a central role in these advances. When stacking layers, new emergent properties can be engineered – or frequently discovered unexpectedly. Within this large

field, the Heinz group has made and is making many key contributions. Here we summarize some of them.

New optical properties of heterostructures: Together with collaborators, Heinz published one of the first papers [226] (cited over 2500 times) investigating the electrical and optical properties of heterostructures formed by stacking two different semiconducting TMDC monolayers on top of one another. A key result was understanding of the type-II band alignment and the associated rapid charge separation across the layers that ensued. The observation of strong quenching in photoluminescence provided a signature from the very rapid (sub-picosecond) charge separation occurring in these model 2D semiconductor heterostructures.

Subsequent studies of the same system (MoS_2/WSe_2) were able to identify emission from the resulting charge-separated interlayer exciton. This work [287], while not the first to report interlayer exciton emission, demonstrated emission that was tunable over more than 100 nm / 100 meV through coupling of the large interlayer exciton dipole moment to a tunable vertical electric field created in a dual gated structure. This emission also spanned a range of relevant for silicon photonic in the near infrared.

Despite the explosion of studies of interlayer excitons in such heterostructures, the Heinz group recently were the first researchers able to directly probe these states by optical absorption [311], as opposed to emission spectroscopy. This was achieved my means of a sensitive electro-modulation technique. The approach revealed new spectroscopic details and importantly allowed the first direct determination of intrinsic radiative lifetimes for interlayer excitations (achieved through analysis of the oscillator strength of the transition and unencumbered by the non-radiative decay channels strongly influence measured emission decay rates). The role of moiré effects on interlayer exciton behavior was also characterized by studies as a function of twist angle of the two layers.

We note that Heinz and collaborators published one of the first papers to recognize the role of the interlayer twist angle in defining the properties of heterostructures [218]. In this work, a precursor of the later boom in investigations of moiré heterostructures, key concepts such as variation in local strain and its effect on the electronic and optical properties were already developed and used to explain the twist-angle dependent response of a homobilayer of MoS_2.

Ultrafast dynamics of excited states: Heinz and collaborators have also developed and applied powerful new optics-based probes to understand fully the dynamics and steps be which interlayer charge separation occurs following the creation of interlayer excitons, including rates of electronic and vibrational relaxation of the system as the excess energy of higher-lying interlayer state relaxes into the lower-energy interlayer state [278]. Two new and complementary techniques have been developed. The charge transfer step was recorded in a very direct fashion by measuring the time evolution of the interlayer current flow through the transient THz emission. This was captured in a pump-probe measurement, with the THz transient, following directly the current flow in the near field, being determined by the free-space electro-optic sampling developed by the Heinz group earlier (as discussed above). A complementary view of the process was achieved in collaborative experiments using time-resolved electron diffraction as a probe [321,327]. This approach yielded a layer-specific determination of phonon populations through the Debye-Waller factor seen in the corresponding diffraction pattern. With the available time resolution of ~ 100 fs, the build-up and eventual equilibration of the phonon degree of freedom could be followed independently of the electronic degree of freedom,

Quantum control and metrology of excitons in 2D semiconductors:

The ability of 2D semiconductors to host stable excitons and exciton complexes suggests that this may be developed as a solid—state platform for quantum information science and quantum simulation. It has the potential to capture investigations currently performed with atoms, but in a convenient and robust platform with stronger interactions and higher temperature scales. Some of the recent work in the Heinz group has been exploring underlying issues to this end. One example of such precise exciton metrology is the use of time-resolved ARPES (angle-resolved photoemission) to gain deeper insight into the excitonic states. Through a collaboration with the Dani group (OIST, Japan), this method has succeeded not only identifying momentum-dark excitons and their dynamics [293], but also in directly imaging the exciton wavefunction through precise measurements of the momentum-space distribution of the photoemitted electrons [298]. Most recently, the approach has directly imaged both the electron and hole components of the wavefunction - the former through the momentum-resolved photoemitted electrons and the latter through the absence of photoemitted electrons [308]. This has yielded a precise characterization of both the wavefunction of an interlayer exciton and of its localization in the interlayer moiré potential of a twisted heterobilayer [308].

The atom-like character of excitons was also investigated in studies of strong-field perturbates to excitonic states in 2D semiconductors. Through the use of a strong IR field to dress the excitons, new Floquet replicas of the excitonic states were readily identifiable in broadband transient absorption spectroscopy [322].

In a complementary line of investigations, research has developed methods by which individual excitons can be localized with nanometer precision. One approach has involved highly localized strain control through patterning of the substrate and the creation of a conformal profile for the 2D semiconductor. Applying this method to $MoSe_2$ has produced site-controllable quantum emitters, as demonstrated by photon correlation ($g^{(2)}$) measurements and the creation of arrays of emitters [295]. Another promising scheme, developed in a collaboration with NTT Research, has made use of strongly localized in-plane DC fields to trap excitons in a fashion analogous to that used with atoms and intensity gradients. The method has led to the creation of nanometer scale 0- and 1-traps and the observation of different quantum-confined translational states of the excitons [330]. External dynamic control of the exciton trap depths and tuning of exciton emission energies has been achieved in this promising platform.

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