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PROFESSIONAL EXPERIENCE

- **University of California, Riverside (UCR)**
  Assistant Professor (07/2015 – Present)
- **Massachusetts Institute of Technology (MIT)**
  Postdoc (08/2012 – 06/2015)
  Adviser: Nuh Gedik
  Research topics: Investigation of 2D materials by terahertz and Raman spectroscopy
- **Columbia University**
  Postdoc (01/2012 – 08/2012)
  Ph.D. in Physics (09/2006 – 02/2011)
  Adviser: Tony F. Heinz
  Thesis: "Investigations of the electronic, vibrational and structural properties of single and few-layer graphene"
- **Hong Kong University of Science and Technology (HKUST)**
  M.Phil. in Physics (01/2005 – 08/2006)
  Adviser: Michael M. T. Loy
  Thesis: "Optical properties of InGaN/GaN multiple quantum well light emitting diodes"
  B.S. in Physics & Mathematics (Dual Degree) (09/2002 – 12/2004)

HONORS AND AWARDS

- NSF CAREER Award (2020)
- The Young Scientist Best Poster Award, Gordon Research Conference on Ultrafast Phenomena in Cooperative System, Galveston, Texas (2010)

FULL PUBLICATION LIST (updated in Feb 2022)

Total citations: 7037 (Google Scholar); h-index: 31
Lui group website: http://www.lui.ucr.edu
Google scholar website: https://scholar.google.com/citations?user=wl75x9cAAAAJ&hl=en

44. M. Altaiary, E. Liu, C. T. Liang, F. C. Hsiao, J. van Baren, T. Taniguchi, K. Watanabe, N. Gabor, Y. C. Chang & **C. H. Lui**, "*Electrically switchable intervalley excitons with strong two-phonon scattering in bilayer* WSe_2", Accepted by ***Nano Lett.,*** Preprint at ***arXiv***

2101.11161 (Link)

43. E. Liu, J. van Baren, Z. Lu, T. Taniguchi, K. Watanabe, D. Smirnov, Y. C. Chang & **C. H. Lui**, "*Exciton-polaron Rydberg states in monolayer $MoSe_2$ and WSe_2*", ***Nature Communications*** 12, 6131 (2021) (Link)

42. E. Liu, T. Taniguchi, K. Watanabe, N. Gabor, Y. T. Cui & **C. H. Lui**, "*Excitonic and valley-polarization signatures of fractional correlated electronic phases in a WS_2/WSe_2 moiré superlattice*", ***Phys. Rev. Lett.*** 127 037402 (2021) (Link)

41. E. Liu, E. Barré, J. van Baren, M. Wilson, T. Taniguchi, K. Watanabe, Y. T. Cui, N. M. Gabor, T. F. Heinz, Y. C. Chang & **C. H. Lui**, "*Signatures of moiré trions in $WSe_2/MoSe_2$ heterobilayers*", ***Nature*** 594, 46–50 (2021) (Link)

40. X. Wang, J. Cao, Z. Lu, A. Cohen, H. Kitadai, T. Li, Q. Tan, M. Wilson, **C. H. Lui**, D. Smirnov, S. Sharifzadeh & X. Ling, "*Spin-induced linear polarization of photoluminescence in antiferromagnetic van der Waals crystals*", ***Nature Materials*** 10.1038 (2021) (Link)

39. W. Li, H. Tian, J. van Baren, A. Berges, M. Altaiary, E. Liu, E. Bekyarova, **C. H. Lui**, J. Liu, & C. J. Bardeen, "*Hexagonal Boron Nitride Encapsulation of Organic Microcrystals and Energy-Transfer Dynamics*", ***J. Phys. Chem. C*** 124, 38, 21170–21177 (2020) (Link).

38. E. Liu, J. van Baren, T. Taniguchi, K. Watanabe, N. Gabor, Y. C. Chang & **C. H. Lui**, "*Multipath optical recombination of intervalley dark excitons and trions in monolayer WSe_2*", ***Phys. Rev. Lett.*** 124, 196802 (2020) (Link)

37. E. Liu, J. van Baren, T. Taniguchi, K. Watanabe, D. Smirnov, Y. C. Chang & **C. H. Lui**, "*Landau-quantized excitonic absorption and luminescence in a monolayer valley semiconductor*", ***Phys. Rev. Lett.*** 124, 097401 (2020) (Link)

36. W. Li, J. van Baren, A. Berges, E. Bekyarova, **C. H. Lui** & C. J. Bardeen, "*Shaping Organic Microcrystals Using Focused Ion Beam Milling*", ***Cryst. Growth Des.*** 2020, 20, 3, 1583-1589 (2020) (Link)

35. E. Liu, J. van Baren, Z. Lu, T. Taniguchi, K. Watanabe, D. Smirnov, Y. C. Chang & **C. H. Lui**, "*Chiral-phonon replicas of dark excitonic states in monolayer WSe_2*", ***Phys. Rev. Research*** 1, 032007(R) (2019) (Link)

34. E. Liu, J. van Baren, Z. Lu, M. M. Altaiary, T. Taniguchi, K. Watanabe, D. Smirnov, & **C. H. Lui**, "*Gate tunable dark trions in monolayer WSe_2*", ***Phys. Rev. Lett***. 123, 027401 (2019) (Link)

33. E. Liu, J. van Baren, T. Taniguchi, K. Watanabe, Y. C. Chang & **C. H. Lui**, "*Magneto-photoluminescence of exciton Rydberg states in monolayer WSe_2*", ***Phys. Rev. B*** 99, 205420 (2019) (Editor's Suggestion) (Link)

32. J. van Baren, G. Ye, J. A. Yan, Z. Ye, P. Rezaie, P. Yu, L. Zheng, R. He & **C. H. Lui**, "*Stacking-dependent interlayer phonons in 3R and 2H MoS_2*", ***2D Materials*** 6, 025022 (2019) (Link)

31. **C. H. Lui**, "*Chapter 4: Raman Spectroscopy of van der Waals Heterostructures*", Book title: Raman Spectroscopy of Two-Dimensional Materials, Springer (2019) (Link)

30. Q. Ma, **C. H. Lui**, J. C. W. Song, Y. Lin, J. F. Kong, Y. Cao, T. H. Dinh, N. L. Nair, W. Fang, K. Watanabe, T. Taniguchi, S. Y. Xu, J. Kong, T. Palacios, N. Gedik, N. M. Gabor & P. Jarillo-Herrero, "*Giant intrinsic photoresponse in pristine graphene*", ***Nature***

Nanotechnology 14, 145–150 (2019) (Link)

29. P. Xia, Z. Liang, M. Mahboub, J. van Baren, **C. H. Lui**, J. Jiao, K. R. Graham & M. L. Tang, "*Surface Fluorination for Controlling the PbS Quantum Dot Bandgap and Band Offset*", ***Chemistry of Materials*** 30, 4943-4948 (2018) (Link)

28. M. Mahboub, P. Xia, J. van Baren, X. Li, **C. H. Lui**, & M. L. Tang, "*Midgap states in PbS quantum dots induced by Cd and Zn enhance photon upconversion*" ***ACS Energy Lett.*** 3, 767-772 (2018) (Link)

27. E. J. Sie, A. Steinhoff, C. Gies, **C. H. Lui**, Q. Ma, M. Rosner, G. Schonhoff, F. Jahnke, T. O. Wehling, Y.-H. Lee, J. Kong, P. Jarillo-Herrero, & N. Gedik, *"Observation of exciton redshift–blueshift crossover in monolayer WS_2"* ***Nano Lett.*** 17, 4210-4216 (2017) (Link)

26. E. J. Sie, **C. H. Lui**, Y.-H. Lee, L. Fu, J. Kong & N. Gedik, "*Large, valley-exclusive Bloch-Siegert shift in monolayer WS_2*", ***Science*** 355, 1066-1069 (2017) (Link)

25. E. J. Sie, **C. H. Lui**, Y.-H. Lee, J. Kong & N. Gedik, "*Observation of intervalley biexcitonic optical Stark effect in monolayer WS_2*" ***Nano Lett.*** 16, 7421–7426 (2016) (Link)

24. R. He, J. van Baren, J.-A. Yan, X. Xi, Z. Yi, G. Ye, I-H. Lu, S. M. Leong & **C. H. Lui**, "*Interlayer breathing and shear modes in $NbSe_2$ atomic layers*" ***2D Materials*** 3, 031008 (2016) (Link)

23. R. He, J. A. Yan, Z. Yin, Z. Ye, G. Ye, J. Cheng, J. Li & **C. H. Lui**, "*Coupling and stacking order of ReS_2 atomic layers revealed by ultralow-frequency Raman spectroscopy*" ***Nano Lett.*** 16, 1404−1409 (2016) (Link)

22. Q. Ma, T. Anderson, N. Nair, N. Gabor, M. Massicotte, **C. H. Lui**, A. Young, W. Fang, K. Watanabe, T. Taniguchi, J. Kong, N. Gedik, F. Koppens & P. Jarillo-Herrero, "*Tuning ultrafast electron thermalization pathways in a van der Waals heterostructure*" ***Nature Physics*** 12, 455-459 (2016) (Link)

21. **C. H. Lui**, Z. Ye, C. Ji, K.-C. Chiu, C.-T. Chou, T. I. Andersen, C. Means-Shively, H. Anderson, J.-M. Wu, T. Kidd, Y.-H. Lee & R. He, "*Observation of interlayer phonon modes in van der waals heterostructures*", ***Phys. Rev. B*** 91, 165403 (2015) (Link)

20. **C. H. Lui**, Z. Ye, C. Keiser, E. B. Barros & R. He, "*Stacking-dependent shear modes in trilayer graphene*", ***App. Phys. Lett.*** 106, 041904 (2015) (Link)

19. **C. H. Lui**, A. J. Frenzel, D. Pilon, Y. H. Lee, X. Ling, G. M. Akselrod, J. Kong & N. Gedik, "*Trion-induced negative photoconductivity in monolayer MoS_2*", ***Phys. Rev. Lett.*** 113, 166801 (2014) (Link)

18. **C. H. Lui*,** Z. Ye*, C. Keiser, X. Xiao & R. He, "*Temperature-activated layer-breathing vibrations in few-layer graphene*", ***Nano Lett.*** *14, 4615-4621* (2014) (†co-corresponding author) (Link)

17. A. J. Frenzel, **C. H. Lui**, Y. C. Shin, J. Kong & N. Gedik, "*Semiconducting-to-metallic photoconductivity crossover and temperature-dependent Drude weight in graphene*", ***Phys. Rev. Lett.*** 111, 127401 (2014) (Link)

16. D. V. Pilon, **C. H. Lui**, T. H. Han, D. Shrekenhamer, A. J. Frenzel, W. J. Padilla, Y. S. Lee

& N. Gedik, "*Spin induced optical conductivity in the spin liquid candidate herbertsmithite*", ***Phys. Rev. Lett.*** 111, 127401 (2013) (Link)

15. A. J. Frenzel, **C. H. Lui**, W. Fang, N. L. Nair, P. K. Herring, P. Jarillo-Herrero, J. Kong & N. Gedik, "*Observation of suppressed terahertz absorption in photoexcited graphene*", ***Appl. Phys. Lett***. 102, 113111 (2013) (Link)

14. **C. H. Lui**, E. Cappelluti, Z. Q. Li & T. F. Heinz. "*Tunable infrared phonon anomalies in trilayer graphene*", ***Phys. Rev. Lett.*** 110, 185504 (2013) (Link)

13. **C. H. Lui** & T. F. Heinz. "*Measurement of layer breathing mode vibrations in few-layer graphene*", ***Phys. Rev. B (Rapid Communication)*** 87, 121404(R) (2013) (Link)

12. D. Boschetto, L. M. Malard, **C. H. Lui**, K. F. Mak, Z. Q. Li, H. G. Yan & T. F. Heinz. "*Real-time observation of interlayer vibrations in bilayer and few-layer graphene*", ***Nano Lett.*** *13, 4620-4623* (2013) (Link)

11. **C. H. Lui**, L. M. Malard, S. H. Kim, G. Lantz, F. E. Laverge, R. Saito & T. F. Heinz. "*Observation of layer-breathing mode vibrations in few-layer graphene through combination raman scattering*", ***Nano Lett.*** 12, 5539-5544 (2012) (Link)

10. J. Shim*, **C. H. Lui***, T. Y. Ko, Y. Yu, P. Kim, T. F. Heinz & S. Ryu. "*Water-gated charge doping of graphene induced by mica substrates*", ***Nano. Lett.*** 12, 648-654 (2012) (Link)

9. Z. Q. Li, **C. H. Lui**, E. Cappelluti, L. Benfatto, K. F. Mak, G. L. Carr, J. Shan & T. F. Heinz. "*Structure-dependent fano resonances in the intrafred spectra of phonons in few-layer graphene*", ***Phys. Rev. Lett.*** 108, 156801 (2012) (Link)

8. **C. H. Lui**, Z. Q. Li, K. F. Mak, E. Cappelluti & T. F. Heinz. "*Observation of an electrically tunable band gap in trilayer graphene*", ***Nature Physics*** 7, 944-947 (2011) (Link)

7. K. Sato, J. S. Park, R. Saito, C. Cong, T. Yu, **C. H. Lui**, T. F. Heinz, G. Dresselhaus & M. S. Dresselhaus. "*Raman spectra of out-of-plane phonons in bilayer graphene*", ***Phys. Rev. B*** 84, 035419 (2011) (Link)

6. **C. H. Lui**, K. F. Mak, J. Shan & T. F. Heinz. "*Ultrafast photoluminescence from graphene*", ***Phys. Rev. Lett.*** 105, 127404 (2010) (Link)

5. **C. H. Lui**, Z. Q. Li, Z. Chen, P. V. Klimov, L. E. Brus & T. F. Heinz. "*Imaging stacking order in few-layer graphene*", ***Nano Lett.*** 11, 164-169 (2010) (Link)

4. K. F. Mak, **C. H. Lui** & T. F. Heinz. "*Measurement of the thermal conductance of the graphene/SiO_2 interface*", ***App. Phys. Lett.*** 97, 221904 (2010) (Link)

3. **C. H. Lui**, L. Liu, K. F. Mak, G. W. Flynn & T. F. Heinz. "*Ultraflat graphene*", ***Nature*** 462, 339-341 (2009) (Link)

2. K. F. Mak, **C. H. Lui**, J. Shan & T. F. Heinz. "*Observation of an electric-field-induced band gap in bilayer graphene by infrared spectroscopy*", ***Phys. Rev. Lett.*** *102*, 256405 (2009) (Link)

1. K. F. Mak, M. Y. Sfeir, Y. Wu, **C. H. Lui**, J. A. Misewich & T. F. Heinz. "*Measurement of the optical conductivity of graphene*", ***Phys. Rev. Lett***. 101, 196405 (2008) (Link)

LIST OF PRESENTATIONS OF CHUN HUNG LUI

Presentations after joining UC Riverside

59. 02/02/2022 Seminar at UC San Diego
Title: Optical spectroscopy of novel excitonic states and electronic phases in 2D semiconductors and moiré superlattices

58. 01/14/2022 The 51st Winter Colloquium on the Physics of Quantum Electronics (Invited talk, online presentation through Zoom)
Title: Signatures of moiré trions in $WSe_2/MoSe_2$ heterobilayers

57. 10/28/2021 UC Riverside Colloquium (Zoom)
Title: Optical spectroscopy of novel excitonic states and electronic phases in 2D semiconductors and moiré superlattices
Link of recorded presentation:
https://www.youtube.com/watch?v=MSdhTcqmNhE

56. 05/11/2021 CLEO (Invited talk; online presentation through Zoom)
Title: Optical spectroscopy of excitonic states in two-dimensional semiconductors and heterostructures
Service in CLEO: Presiding Session FTu4I: Quantum Materials Studied by Novel Ultrafast Spectroscopy and Microscopy in 05/11/2021

55. 4/28/2021 Colloquium for Boston College (Remote online presentation through Zoom)
Title: Optical spectroscopy of novel electronic and excitonic states in 2D semiconductors and moiré superlattices

54. 03/16/2021 APS March Meeting (Online presentation through Zoom)
Title: Observation of roton effect in exciton polarons

53. 08/20/2020 SPIE Nanoscience + Engineering, 2020, Online Only (Video presentation)
Title: Novel spin- and valley-dependent excitonic states in atomically thin semiconductor devices
Link of recorded presentation: https://doi.org/10.1117/12.2570597

52. 03/04/2019 APS March Meeting, Boston, Massachusetts
Title: Observation of trion Rydberg states in monolayer $MoSe_2$

51. 01/25/2018 Colloquium; Department of Physics and Astronomy, University of California Riverside
Title: Observation of Valley-Exclusive Bloch-Siegert Shift in Monolayer WS_2

50. 12/04/2017 Colloquium; Department of Electrical and Computer Engineering, University of California Riverside
Title: Observation of Valley-Exclusive Bloch-Siegert Shift in Monolayer WS_2

49. 10/09/2017 The Great Scientific Exchange (SciX) Conference, Reno, Nevada
Title: Coupling and Stacking Order of ReS_2 Atomic Layers Revealed by Ultralow-Frequency Raman Spectroscopy

48. 03/15/2017 APS March Meeting, New Orleans, Louisiana
Title: Coupling and Stacking Order of ReS_2 Atomic Layers Revealed by Ultralow-Frequency Raman Spectroscopy

47. 05/18/2016 Seminar; University of California San Diego
Title: Probing the interlayer interactions in 2D materials and heterostructures by ultralow-frequency Raman spectroscopy

46. 04/2016 Colloquium; University of California Riverside
Title: Shedding light on two-dimensional electrons in graphene and beyond

45. 01/20/2016 Southern California Condensed Matter (SoCal) Seminar; University of California Riverside
Title: Coupling and Stacking Order of ReS_2 Atomic Layers Revealed by Ultralow-Frequency Raman Spectroscopy

Presentations before joining UC Riverside

44. 05/2015 Seminar; University of California Berkeley
Title: Terahertz trion and phonon properties of 2D materials

43. 05/07/2015 Seminar; Boston University
Title: Unconventional photoconductivity in 2D materials revealed by terahertz spectroscopy

42. 04/09/2015 Colloquium; University of Nevada Las Vegas
Title: Shedding light on two-dimensional electrons in graphene and beyond

41. 04/07/2015 Colloquium; New York University, New York
Title: Shedding light on two-dimensional electrons in graphene and beyond

40. 03/26/2015 Colloquium; Delft University of Technology (TU Delft), Delft, Netherlands
Title: Shedding light on two-dimensional electrons in graphene and beyond

39. 03/24/2015 Colloquium; University of Tennessee, Knoxville, Tennessee
Title: Shedding light on two-dimensional electrons in graphene and beyond

38. 03/09/2015 Colloquium; University of Iowa, Iowa City, Iowa
Title: Shedding light on two-dimensional electrons in graphene and beyond

37. 03/06/2015 Colloquium; Academia Sinica, Taiwan
Title: Shedding light on two-dimensional electrons in graphene and beyond

36. 03/04/2015 Colloquium; National Taiwan University, Taiwan
Title: Shedding light on two-dimensional electrons in graphene and beyond

35. 02/27/2015 Colloquium; City College in New York City
Title: Shedding light on two-dimensional electrons in graphene and beyond

34. 02/24/2015 Colloquium; University of Arkansas Fayetteville
Title: Shedding light on two-dimensional electrons in graphene and beyond

33. 02/23/2015 Seminar; University of California Riverside
Title: Shedding light on two-dimensional electrons in graphene and beyond

32. 02/19/2015 Colloquium; University of California Merced
Title: Shedding light on two-dimensional electrons in graphene and beyond

31. 02/17/2015 Colloquium; University of Central Florida, Orlando, Florida
Title: Shedding light on two-dimensional electrons in graphene and beyond

30. 02/12/2015 Colloquium; University of Connecticut, Storrs, Connecticut
Title: Shedding light on two-dimensional electrons in graphene and beyond

29. 02/08/2015 Colloquium; Michigan State University, East Lansing, Michigan
Title: Shedding light on two-dimensional electrons in graphene and beyond

28. 02/04/2015 Colloquium; Peking University, China
Title: Shedding light on two-dimensional electrons in graphene and beyond

27. 02/02/2015 Colloquium; Shanghai Jiao Tong University, Shanghai, China
Title: Shedding light on two-dimensional electrons in graphene and beyond

26. 02/02/2015 Seminar; Shanghai Jiao Tong University, Shanghai, China
Title: Ultrafast optical spectroscopy of graphene and beyond

25. 01/15/2015 Colloquium; Vanderbilt University, Nashville, Tennessee
Title: Shedding light on two-dimensional electrons in graphene and beyond

24. 01/12/2015 Colloquium; University of California Santa Cruz
Title: Shedding light on two-dimensional electrons in graphene and beyond

23. 12/06/2014 Colloquium; University of Texas Dallas
Title: Shedding light on two-dimensional electrons in graphene and beyond

22. 03/28/2014 Seminar; Institute for Theoretical Atomic Molecular and Optical Physics (ITAMP), Harvard University
Title: Ultrafast terahertz probe of transient photoconductivity in single-layer graphene and MoS_2

21. 03/03/2014 APS March Meeting, Denver, Colorado
Title: Observation of negative terahertz photoconductivity in monolayer MoS_2 under femtosecond laser excitation

20. 03/05/2014 APS March Meeting, Denver, Colorado
Title: Tunable infrared phonon anomalies in trilayer graphene

19. 02/26/2014 Colloquium; University of Alabama Tuscaloosa
Title: Shedding light on two-dimensional electrons in graphene

18. 12/05/2013 Seminar; Chinese University of Hong Kong, Hong Kong
Title: Ultrafast optical spectroscopy of graphene and beyond

17. 12/04/2013 Colloquium; Chinese University of Hong Kong, Hong Kong
Title: Shedding light on two-dimensional electrons in graphene

16. 11//28/2013 Colloquium; Hong Kong University, Hong Kong
Title: Shedding light on two-dimensional electrons in graphene

15. 11/11/2013 Colloquium; Carnegie Mellon University, Pittsburgh, Pennsylvania
Title: Shedding light on two-dimensional electrons in graphene

14. 03/20/2013 Invited talk; APS March Meeting, Baltimore, Maryland
Title: Probing electronic and vibrational interactions in few-layer graphene by optical spectroscopy

13. 06/2012 Seminar; Hong Kong University of Science and Technology, Hong Kong
Title: Probing the interactions of few-layer graphene by optical spectroscopy

12.	05/15/2012	Seminar; Massachusetts Institute of Technology Title: Probing interactions in graphene by optical spectroscopy
11.	12/08/2011	ONR/AFOSR Joint Graphene MURI Review, Monterey, California Title: Real-time study of the interlayer shearing mode in few-layer graphene
10.	11/10/2011	Seminar; Cornell University, Ithaca, New York Title: Probing the electronic and vibrational properties of trilayer graphene by optical spectroscopy
9.	07/2011	Seminar; University of California Berkeley Title: Investigations of the electronic, vibrational and structural properties of single and few-layer graphene
8.	07/2010	The National Research Initiative, Columbia University, New York Title: The optical and morphological properties of graphene layers
7.	04/19-23/ 2010	Graphene Week Conference, College Park, Maryland Title: Ultrafast photoluminescence from graphene
6.	03/04/2010	Invited talk for *The Young Scientist Best Poster Award* Gordon Research Conference on Ultrafast Phenomena in Cooperative System, Galveston, Texas Title: Light emission from graphene induced by femtosecond laser pulses
5.	03/19/2009	APS March Meeting, Pittsburgh, Pennsylvania Title: Atomically Flat Graphene on Mica Substrates
4.	03/16/2009	APS March Meeting, Pittsburgh, Pennsylvania Title: Dependence of the low-energy electronic structure of multi-layer graphene on stacking order probed by infrared absorption
3.	12/2008	Seminar; Columbia University, New York Title: Atomically thin graphene on mica
2.	03/11/2008	APS March Meeting, New Orleans, Louisiana Title: Experimental measurement of ultrafast carrier dynamic in mono- and multi-layer graphene samples
1.	03/10/2008	APS March Meeting, New Orleans, Louisiana Title: Measurement of the thermal conductance at the graphene-quartz interface by optical pump-probe spectroscopy

SUMMARY OF KEY RESEARCH ACCOMPLISHMENTS FOR CHUN HUNG LUI

(After joining UC Riverside)

- **Observation of the signatures of moiré trions:** Moiré superlattices formed by van der Waals materials can produce fascinating phenomena, such as Mott insulation, superconductivity, and generalized Wigner crystallization. When confined by a moiré superlattice, a new class of excitons emerges, holding promises for realizing artificial excitonic crystals and novel quantum optical effects. When such moiré excitons are coupled to the charge carriers, complex correlated states may arise. However, no experimental evidence exists for charge-coupled moiré exciton states, nor have their properties been predicted by theory by the time of our work. We have observed the experimental signatures of trions confined by the moiré superlattice potential in $WSe_2/MoSe_2$ heterobilayers. The moiré trions exhibit sharp emission lines with complex charge-density dependence, in stark contrast to the behavior of conventional trions. Remarkably, the moiré trions exhibit more than one emission band due to trion recombination with the remaining carrier residing in different moiré minibands. By filling the minibands with carriers, we can turn on and off these moiré trion emission bands. Such moiré trions open new opportunities to explore correlated electronic and excitonic states in moiré superlattices. [***Nature*** 594, 46–50 (2021)]
- **Observation of excitonic and valley-polarization signature of fractional correlated electronic phases in a moiré superlattice:** In semiconducting moiré superlattices, the strong electron-electron repulsion and the confinement effect of the moiré potential can drive the electrons into crystalline phases, including the stripe phases and generalized Wigner crystals, at fractional fillings of the moiré superlattices. Our group has investigated the influence of such correlated electron phases on the excitonic states in a WSe_2/WS_2 heterobilayer moiré superlattice at gate-tunable charge filling. We observe absorption modulation of three intralayer moiré excitons at filling factors $\nu = 1/3$ and 2/3. We also observe luminescence modulation of interlayer trions at a number of fractional filling factors, including $\nu = -3/2$, 1/4, 1/3, 2/5, 2/3, 6/7, 5/3. Remarkably, the valley polarization of interlayer trions is suppressed at some fractional fillings. These results demonstrate that electron crystallization can modulate the absorption, emission, and valley dynamics of the excitonic states in a moiré superlattice. [***Phys. Rev. Lett.*** 127, 037402 (2021)]
- **Investigation of exciton-polaron Rydberg states in monolayer $MoSe_2$ and WSe_2:** Semiconductor research has commonly used the trion picture to describe the coupling between exciton and Fermi sea. In this simple picture, the exciton captures a carrier from the Fermi sea to form a three-body bound state (trion). In our study of excitonic Rydberg states in charged monolayer $MoSe_2$ and WSe_2, we show that the trion model fails to explain the robust binding of the excited states as well as the carrier-density dependence of the binding energy. Instead, our experimental results and theoretical simulation support the formation of exciton polarons, which are complex quasiparticles formed by dressing an exciton with a cloud of electron-hole polarization. The results gave us much insight into the nature of excitonic states in charged monolayer semiconductors. [***Nature Communications*** 12, 6131 (2021)]
- **Switchable intervalley excitons with strong two-phonon scattering in bilayer WSe_2:** We report the observation of QΓ intervalley exciton in bilayer WSe_2 devices encapsulated by boron nitride. The QΓ exciton resides at ~18 meV below the QK exciton. The QΓ and QK excitons exhibit different Stark shifts under an out-of-plane electric field due to their different

interlayer dipole moments. By controlling the electric field, we can switch their energy order and control which exciton dominates the luminescence of bilayer WSe_2. Remarkably, both QΓ and QK excitons exhibit unusually strong two-phonon replicas, which are comparable to or even stronger than the one-phonon replicas. By detailed theoretical simulation, we reveal the existence of numerous (≥14) two-phonon scattering paths involving (nearly) resonant exciton-phonon scattering in bilayer WSe_2. To our knowledge, such electric-field-switchable intervalley excitons with strong two-phonon replicas have not been found in any other atomically thin 2D semiconductors. They make bilayer WSe_2 a distinctive valleytronic material with potential novel applications. [***arXiv*** 2101.11161 (2020)]

- **Observation of multipath optical recombination of intervalley dark excitons and trions in monolayer WSe_2:** This is the first demonstration that dark trions (or exciton polarons) in monolayer valley semiconductors can decay through both intravalley and intervalley transitions. These two transitions are coupled to zone-center and zone-corner chiral phonons, respectively, to produce distinct phonon replicas. Also, we reveal both the defect-assisted and phonon-assisted optical recombination of the intervalley dark excitons. The observed multipath optical decays of dark excitons and trions provide insight into the internal quantum structure of trions and the complex excitonic interactions with defects and chiral phonons in monolayer valley semiconductors. [***Phys. Rev. Lett.*** 124, 196802 (2020)]
- **Landau-quantized excitonic absorption and luminescence in a monolayer valley semiconductor:** We observe charge-density-dependent quantum oscillations in the excitonic absorption and luminescence of monolayer WSe_2 under magnetic field. Valley-selective quantum oscillations occur for both the exciton and trions (or exciton-polarons), and reveal distinct influence from the intravalley and intervalley coupling between excitons and Landau levels (LLs). We observe spin- and valley-polarized LLs with filling factors n = –6 to +1, including the Berry-curvature-induced n = ±0 LLs of massive Dirac fermions. The LL filling produces quantum-Hall-like plateaus in the exciton energy shift accompanied with sharp oscillations in the exciton absorption width and magnitude. We also reveal much larger g-factors of the conduction and valence bands than the values predicted by a single-particle model, indicating strong many-body interactions in the system. Our demonstrated complex interplay between Landau quantization, excitonic effects, and many-body interactions provides a new platform to realize novel correlated quantum phenomena. [***Phys. Rev. Lett.*** 124 097401 (2020)]
- **Demonstrating chiral-phonon replicas as valley indicators of 2D dark excitonic states:** Dark excitons and trions (or exciton-polarons) have long valley lifetime but lack the usual valley selection rules of bright excitonic states. The lack of a valley signature severely hinders the study of dark-state valley dynamics. We observe two sets of three chiral-phonon replica luminescent peaks of the dark excitons and trions, which exhibit distinctive valley selection rules. We show that the K-valley dark excitonic states decay into a left-handed chiral phonon and a right-handed photon, whereas the K'-valley dark excitonic states decay into a right-handed phonon and a left-handed photon. These chiral-phonon replicas serve as valley indicators to identify the dark-state valleys for exploring the valley dynamics in monolayer WSe_2 (and possibly also in other 2D semiconductors). [***Phys. Rev. Research*** 1, 032007(R) (2019)]
- **Gate-tunable dark trions in monolayer WSe_2:** This is the first systematic investigation of gate-tunable properties of dark trions in monolayer valley semiconductors. We have measured the photoluminescence from dark exciton and trions (or exciton-polarons) in ultraclean monolayer WSe_2 devices encapsulated by boron nitride. The dark trions can be tuned

continuously between negative and positive trions with electrostatic gating. We reveal their spin-triplet configuration and distinct valley optical emission by their characteristic Zeeman splitting under magnetic field. The dark trion lifetime (~1.3 ns) is two orders of magnitude longer than the bright trion lifetime (~10 ps) and can be tuned between 0.4 and 1.3 ns by gating. Such robust, optically detectable, and gate tunable dark trions hold promises for realizing trion transport in two-dimensional materials. [***Phys. Rev. Lett.*** 123, 027401 (2019)]

- **Magneto-photoluminescence of exciton Rydberg states in monolayer WSe_2:** Monolayer WSe_2 hosts a series of exciton Rydberg states denoted by the principal quantum number $n = 1$, 2, 3, etc. While most research focuses on their absorption properties, their optical emission is also important but much less studied. We have measured the photoluminescence from the 1s – 5s exciton Rydberg states in monolayer WSe_2 under magnetic fields from −31 to 31 T. The exciton Rydberg states exhibit similar Zeeman shifts but distinct diamagnetic shifts from each other. From their luminescence spectra, Zeeman shifts, and diamagnetic shifts, we deduce the binding energies, g-factors, and radii of the 1s – 4s exciton states. [***Phys. Rev. B*** 99, 205420 (2019); *Editor's Suggestion*]
- **Stacking-dependent interlayer phonons in 3R and 2H MoS_2:** This is the first investigation of interlayer phonon modes in MoS_2 with pure 3R stacking order. By using ultralow-frequency Raman spectroscopy, we measure and compare the interlayer shear and breathing modes between 3R and 2H MoS_2 from 2 to 13 layers. The shear modes show striking stacking-order dependence, which allows us to identify both the layer thickness and stacking order. We have also established an elegant analytic theory to simulate the Raman spectra. Our research sets a basis for further research of 3R-stacked transition metal dichalcogenide (TMD) materials. [***2D Materials*** 6, 025022 (2019)]
- **Interlayer phonon modes in few-layer ReS_2 and $NbSe_2$:** These are the first comprehensive investigations of interlayer phonon modes in ReS_2 and $NbSe_2$, two special types of 2D materials. ReS_2 features strong in-plane lattice distortion, in contrast to other isotropic 2D materials. By measuring its breathing mode and non-degenerate shear modes, we determine its strength of anisotropy, interlayer coupling and stacking order. Our results resolve a long-lasting controversy about the interlayer coupling of ReS_2. On the other hand, $NbSe_2$ is a metallic 2D material with charge density waves. We have measured its interlayer modes at low temperature and investigated the possible influence of charge density waves on the interlayer vibration modes. [***Nano Lett.*** 16, 1404−1409 (2016); ***2D Materials*** 3, 031008 (2016)]
- **Discovery of a large, valley-exclusive Bloch-Siegert shift in monolayer WS_2:** This is the first observation of Bloch-Siegert shift in any extensive condensed matter systems. Coherent interaction with off-resonance light can be used to shift the energy levels of atoms, molecules, and solids. The dominant effect is the optical Stark shift, but there is an additional contribution from the Bloch-Siegert shift that has eluded direct and exclusive observation in solids. We observe an exceptionally large Bloch-Siegert shift in monolayer WS_2 under infrared optical driving. By controlling the light helicity, we could confine the Bloch-Siegert shift to occur only at one valley, and the optical Stark shift at the other valley, because the two effects obey opposite selection rules at different valleys. Such a large and valley-exclusive Bloch-Siegert shift allows for enhanced control over the valleytronic properties of 2D materials. [***Science*** 355, 1066-1069 (2017)]

(Before joining UC Riverside)

- **Ultraflat graphene:** Using atomic-force microscopy measurements, we demonstrate that single-layer graphene deposited on atomically flat surfaces of cleaved mica exhibits ultraflat morphology, with a height variation (<30 picometer) indistinguishable from that observed for the surface of cleaved graphite. This study shows that supported graphene is not subject to any intrinsic thermodynamics instability and implies that the much-discussed undulations seen for the usual case of graphene on oxidized silicon simply reflect the substrate morphology, not any intrinsic graphene rippling. Our experiment also inspires the search of other atomically flat substrates, such as hexagonal boron nitride, for high-quality graphene electronics. [***Nature*** 462, 339-341 (2009)]
- **Investigation of the ultrafast dynamics of Dirac fermions in graphene by optical emission spectroscopy:** This is the first report of light emission from pristine graphene. Emission can be observed under excitation by ultrashort (30 fs) laser pulses. Studies of the emission properties induced by single and time-correlated pairs of excitation pulses allow us to learn about ultrafast carrier dynamics in graphene. Systematic analysis and modeling of the photoluminescence spectra reveals relaxation processes of excited charge carriers in time scales from 10 fs to 1 ps. We find that the charge carriers thermalize and cool within a few 10's of femtosecond by the emission of optical phonons, and the equilibrated subsystem of electrons and optical phonons reaches transient temperatures exceeding 3000 K and stays out of equilibrium with the other phonons in the picosecond time scale. [***Phys. Rev. Lett.*** 105, 127404 (2010)]
- **Demonstration of tunable photoconductivity in graphene:** By using time-resolved terahertz spectroscopy, we observe a pronounced transient change of conductivity in graphene under femtosecond laser excitation. The differential conductivity of graphene changes from positive to negative as its charge density is tuned from low to high values by electrical gating. Our experiment resolves the early conflicting results in graphene samples at different doping conditions. It also demonstrates that graphene can controllably exhibit either semiconducting (positive) or metallic (negative) photoconductivity behavior, a remarkable material property for versatile optoelectronic applications. Furthermore, simulations based on a Drude model reveal a non-monotonic temperature dependence of Drude response in graphene, a unique fundamental property of massless Dirac fermions that has been predicted but hitherto unobserved. [***Phys. Rev. Lett.*** 111, 127401 (2014); ***Appl. Phys. Lett.*** 102, 113111 (2013)]
- **Development of optical techniques to characterize the layer thickness and stacking order of few-layer graphene:** We demonstrate that the thickness (1-20 layers) and stacking order (Bernal or rhombohedral stacking) of few-layer graphene can be identified accurately by measuring the infrared absorption spectrum or the Raman spectra of 2D mode and other interlayer phonon modes. In particular, we can conveniently map out the spatial distribution of different stacking orders by using the line shape of Raman 2D-mode. These various optical characterization methods constitute a necessary component to support and accelerate the research of few-layer graphene [***Phys. Rev. Lett.*** 101, 196405 (2008); ***Nano Lett.*** 11, 164-169 (2010); ***Nature Physics*** 7, 944-947 (2011); ***Nano Lett.*** 12, 5539-5544 (2012); ***Phys. Rev. B*** 87, 121404(R) (2013); ***Nano Lett.*** 14, 4615-4621 (2014); ***Appl. Phys. Lett.*** 106, 041904 (2015)]
- **Comprehensive Raman studies of interlayer phonons in few-layer graphene:** By using ultralow-frequency Raman spectroscopy, we observe and identify the interlayer shear modes and breathing modes in few-layer graphene, which involve the tangential and vertical displacement of individual graphene layers, respectively. As these phonons are created by

interlayer couplings, they exhibit great sensitivity to the layer thickness, stacking order and surface conditions of few-layer graphene. For instance, their frequencies evolve systematically with the layer thickness; the shear-mode Raman activity depends critically on the stacking order; the breathing modes are damped by the surface adsorbates but can be activated at high temperature. Although the interlayer modes are difficult to detect due to their ultralow frequency (<10 meV), they can manifest themselves at higher frequencies through the overtone modes and combination modes with other in-plane optical phonons. These higher-order Raman modes are also sensitive to the crystal structure of few-layer graphene and thus serve as effective probes to the material properties [***Phys. Rev. B*** 84, 035419 (2011); ***Nano Lett.*** 12, 5539-5544 (2012); ***Nano Lett.*** 13, 4620-4623 (2013); ***Phys. Rev. B*** 87, 121404(R) (2013); ***Nano Lett.*** 14, 4615-4621 (2014); ***Appl. Phys. Lett.*** 106, 041904 (2015)]

- **Observation of an electrically tunable band gap in few-layer graphene:** We observe the induction of tunable band gap of over 100 meV in bilayer and ABC-stacked trilayer graphene under electrical gating. We demonstrate that the electronic structure of few-layer graphene is highly adjustable by external perturbations, a remarkable material property that allows great flexibility in the design and optimization of graphene devices. In addition, the induced gap is not found in ABA-stacked trilayers, showing that that the tunability of electronic structure depends critically on the stacking sequence of graphene layers. **[*Phys. Rev. Lett.*** 102, 256405 (2009); ***Nature Physics*** 7, 944-947 (2011)]
- **Systematic studies of structure- and doping-dependent infrared phonon anomalies in few-layer graphene:** We observe intense infrared absorption from in-plane optical phonons in few-layer graphene (3 - 6 layers) arising from their coupling to the interband electronic transitions. The phonon spectra depend critically on the layer thickness, stacking order and doping level of graphene. Few-layer samples with rhombohedral (ABC) stacking consistently exhibit larger intensities, more asymmetric lineshapes and stronger doping dependence than those with Bernal (AB) stacking, reflecting the stronger electron-phonon coupling in these systems. Our experiments reveal the distinctive variation of many-body interactions in graphene of differing thickness and stacking order, which can be controlled effectively by external perturbations. [***Phys. Rev. Lett.*** 108, 156801 (2012); ***Phys. Rev. Lett.*** 110, 185504 (2013)]
- **Observation of electrical conduction by trions in monolayer MoS_2:** This is the first report of strong trionic effects on the conductive properties of 2D crystals. By using time-resolved terahertz spectroscopy, we find that the conductivity of monolayer MoS_2 is reduced to only 30 % of its initial value under the excitation of strong laser pulses. This usual phenomenon arises from the strong electrostatic interactions in monolayer MoS_2, where photoexcited electron-hole pairs are bound to the doping-induced free charges to form trions (bound states of two electrons and one hole). The three-fold increase of effective mass of charge carriers thus strongly reduces their conductivity. Our research reveals that charge transport in MoS_2 can be conducted by trions. As trions allow the control of motion of excitons and their psudospins by an electric field, our results pave the way to develop novel excitonic and spintronic devices. [***Phys. Rev. Lett.*** 113, 166801 (2014), Editor's Suggestion]
- **Observation of layer-breathing modes in van der Waals heterostructures:** This is the first report of interlayer phonon modes in van der Waals heterostructures. By using ultralow-frequency Raman spectroscopy, we observe the out-of-plane breathing vibrations between two atomic sheets in the MoS_2/WSe_2 and $MoSe_2/MoS_2$ heterogeneous bilayer structure. The layer-breathing modes exhibit great sensitivity to the separation and relative orientation of the two layers in the heterostructure. Our experiment demonstrates the interlayer phonon modes to be

an effective probe to characterize the interfacial conditions and interlayer interactions in van der Waals heterostructures, and also inspires the fabrication of atomically thin phononic crystals [***Phys. Rev. B*** 91, 165403 (2015)].

- **Optical studies of 2D quantum spin liquids:** A quantum spin liquid is a state of matter in which magnetic spins interact strongly, but quantum fluctuations inhibit long-range magnetic order even at zero temperature. This strongly entangled system is predicted to host exotic elementary excitations that carry only spin and no charge (so-called spinons). We measure the low-frequency optical conductivity of large-area single-crystal herbertsmithite, a promising spin-liquid candidate material, by means of terahertz time-domain spectroscopy. We observe a contribution to the in-plane conductivity from the spinon excitations, with spectral characteristics consistent with the theoretical predictions based on a gapless U(1) Dirac spin liquid. Our results suggest non-negligible interactions between the spinons and charges mediated by a gauge field in a spin liquid, and provide important insight into the nature of the spin ground state in herbertsmithite [***Phys. Rev. Lett.*** 111, 127401 (2013)].

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