Research accomplishment – Jigang Wang

I investigate diverse light-driven coherent and non-equilibrium quantum systems from superconducting, magnetic, and topological materials to nano-junctions and quantum circuits. The scientific driver is to both provide a fundamental understanding of quantum many-body correlations out-of-equilibrium and achieve coherent light-matter control at quantum limit. I implement this vision by developing cutting-edge ultrafast, coherent spectroscopy and nano-imaging tools over a wide frequency spectrum, spanning from terahertz, infrared to ultraviolet. My accomplishments, particularly in coherent and non-equilibrium dynamics of driven quantum systems, provide the linkage between different communities from condensed matter physics and nano-optics to quantum information science, and merge them to break new frontiers. Some of my achievements in studies of light-driven quantum materials are summarized in my APS fellow citation – "For his study of coherent excitations and out-of-equilibrium topological and magnetic phenomena, especially his discoveries of light-induced Weyl and Dirac semimetals and Higgs modes in Iron-based superconductors."

Recent Accomplishment:

- **Light-induced parametric superconductivity**: We demonstrate Higgs coherence tomography of light-controlled superconductivity (Nat Phys 2022). We achieve this by performing the THz multi-dimensional coherent spectroscopy for the first time on superconductors.
- **Coherent and ultrafast manipulation of topological materials:** We discover light induced formation of Dirac (PRX 2020) and Weyl points (Nat Mater 2021), and topology switching using infrared and Raman phonon coherences. We observe frequency-dependent carrier cooling times that differentiate topological surface from bulk contributions (Nat Commun 2019). We report that coherent phonon generation can suppress surface-bulk coupling (npj Quan Mater 2020).
- **Forbidden Anderson pseudo-spin precessions**: we show light--induced subcycle symmetry breaking to induce high harmonic generations forbidden by the equilibrium symmetry and hint long-lived gapless superfluidity (PRL 2020 and Nat Photon 2019).
- **Discovery of new collective modes** in correlated electrons: (1) we discover *hybrid Higgs* mode, a new collective mode driven by interband pairing fluctuations (Nat Commun 2021); we discover spin exciton modes (PRL 2018) and Ising-Nematic fluctuations (Nat Commun 2014) in FeAs superconductors.
- **Quantum quench pre-thermalized quasi-particle states**: we discover a metastable quasi-particle phase with *vanishing* scattering hidden by superconductivity revealed by a THz quench without heating other degrees of freedoms (Nat Mater 2018).
- **THz nano-imaging of energy materials**: We use THz near-field nano-conductivity mapping to: (1) reveal distinct dielectric heterogeneity due to charge trapping and degradation at the single grain boundary level in metal halide perovskite photovoltaic films (ACS photon 2021); (2) reveal a clear Dirac fermion density variation in topological semimetals at sub-20 nm and THz frequency due to local strain heterogeneity (ACS photon 2022).
- **Femtosecond quantum magnetism**: we demonstrate femtosecond quantum spin switching in a colossal magento-resistive manganite during the fs optical pulse (Nature 2013).
- **Broadband terahertz generation in metamaterials:** We showed single-cycle, broadband terahertz (THz) emission up to 4 THz from deep subwavelength structures of split ring resonator metamaterials of a few tens of nanometers (Nat Commun 2014).
- **Femtosecond population inversion** of extremely dense Dirac fermions in graphene monolayer (PRL 2012)
- **Electronic coherence and collective modes in metal halide perovskites**: we use coherent time-frequency visualization methods to discover Rydberg excitons (Nat Commun 2017), Rashba excitons, polarons and phonons (PRL 2020).

References:

- [Nat Phys 2022] L. Luo et al., "Quantum Coherence Tomography of Light–Controlled Superconductivity," **Nature Physics,** 10.1038/s41567-022-01827-1 (2022)
- [PRX 2020] C. Vaswani et al., "Light-Driven Raman Coherence as a Non-Thermal Route to Ultrafast Topology Switching," **Phys. Rev. X** 10, 021013 (2020).
- [Nat Mater 2021] L. Luo, et al., "A Light-induced Phononic Symmetry Switch and Giant Dissipationless Topological Photocurrent in ZrTe5," **Nature Materials,** 20, 329–334 (2021)
- [Nat Commun 2019] L. Luo et al., "Ultrafast Manipulation of Topologically Enhanced Surface Transport Driven by Mid-Infrared and Terahertz Pulses in Bi_2Se_3", **Nature Communications,** 10.1038/s41467-019-08559-6 (2019)
- [npj Quan Mater 2020] L. Luo et al., "Light Control of Surface–Bulk Coupling by Terahertz Vibrational Coherence in a Topological Insulator," **npj Quantum Mater**. **5**, 13 (2020).
- [PRL 2020] C. Vaswani et al., "Terahertz Second Harmonic Generation from Lightwave Acceleration of Symmetry-Breaking Nonlinear Supercurrents", **Physical Review Letters** 124, 207003 (2020).
- [Nat Photon 2019] X. Yang et al., Lightwave-Driven Gapless Superconductivity and Forbidden Quantum Beats by Terahertz Symmetry Breaking. **Nature Photonics**, 13, 707 (2019)
- [Nat Commun 2021] C. Vaswani et al., "Light Quantum Control of Persisting Higgs Modes in Iron-Based Superconductors", **Nature Communications**, 12, 258 (2021).
- [PRL 2018] X. Yang et al., Nonequilibrium Pair Breaking in Ba(Fe1−xCox)2As2Superconductors: Evidence for Formation of a Photoinduced Excitonic State, **Phys. Rev. Lett.** 121, 267001 (2018)
- [Nat Commun 2014] "Ultrafast Observation of Critical Nematic Fluctuations and Giant Magnetoelastic Coupling in Iron Pnictides," **Nature Communications**, 5, 3229 (2014)
- [Nat Mater 2018] X. Yang et al., Terahertz-light quantum tuning of a metastable emergent phase hidden by superconductivity. **Nature Materials.** 17, 586 (2018).
- [ACS photon 2021] R. H. J. Kim, C. Huang, et al., "Terahertz Nano-Imaging of Electronic Strip Heterogeneity in a Dirac Semimetal," **ACS Photonics**, 8, 7, 1873–1880 (2021) (Cover)
- [ACS photon 2022] R. H. J. Kim et al., "Terahertz nano-imaging of perovskite solar cell materials," **ACS Photonics,** 10.1021/acsphotonics.2c00861 (2022) (cover)
- [Nature 2013] T. Li et al., "Femtosecond switching of magnetism via strongly correlated spin–charge quantum excitations," **Nature,** 496**,** 69 (2013)
- [Nat Commun 2014] Liang Luo, Ioannis Chatzakis, Jigang Wang*, Nian Hai Shen, Thomas Koscny and Costas M. Soukoulis, "Broadband Terahertz Generation from Metamaterials," **Nature Communications**, 5, 3055 (2014).
- [PRL 2012] 26) T. Li et al., "Femtosecond population inversion and stimulated emission of dense Dirac fermions in graphene," **Physical Review Letters**, 108, 167401, (2012); *Editor's suggestion*
- [Nat Commun 2017] Liang Luo et al., "Directly Revealing Dark Excitonic Ground States of Selective Chirality Single-Walled Carbon Nanotubes via Ultrafast Terahertz Spectroscopy," **Nature Communications,** 8, 15565 doi: 10.1038/ncomms15565 (2017).
- [PRL 2020] Z. Liu, et al., Discovery of Hidden Rashba Fine Structure by Mode-Selective Quantum Beats in Perovskites, 1905.12373, **Phys. Rev. Lett** (2020).
- [PRL 2015] Liang Luo et al., "Directly Revealing Dark Excitonic Ground States of Selective Chirality Single-Walled Carbon Nanotubes via Ultrafast Terahertz Spectroscopy," **Physical Review Letts**, 114, 107402 (2015)
- [PRL 2010] Jigang Wang et al., "Ultrafast Spectroscopy of Midinfrared Internal Exciton Transitions in Separated Single-Walled Carbon Nanotubes," **Physical Review Letters**, 104, 177401 (2010)
- [Nat Commun2014] "Ultrafast Observation of Critical Nematic Fluctuations and Giant Magnetoelastic Coupling in Iron Pnictides," **Nature Communications**, 5, 3229 (2014)
- [3 *Phys. Rev Lett papers* 2005, 2008, 2010] M. D. Kapetanakis, et al., "Femtosecond Coherent Control of Spins in (Ga,Mn)As Ferromagnetic Semiconductors Using Light," **Physical Review Letters**, 103,

047404 (2009); J. Wang et al., “Ultrafast Enhancement of Ferromagnetism via Photoexcited Holes in GaMnAs”, **Physical Review Letters**, 98, 217401 (2007); J. Wang et al., “Ultrafast Quenching of Ferromagnetism in InMnAs Induced by Intense Laser Irradiation,” **Physical Review Letters**, 95, 167401 (2005)

- [arXiv:2210.07319] R. H. J. Kim et al., "Cryogenic Magneto-terahertz Scanning Near-field Optical Microscope (cm-SNOM)," **arXiv:2210.07319**
- [arXiv:2207.05960] R. H. J. Kim et al.,"Visualizing heterogeneous dipole fields by terahertz light coupling in individual nano-junctions used in transmon qubits," **arXiv:2207.05960**