Parth Bhargava

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EDUCATION

National University of Singapore Aug 2024 – Present (Expected Graduation: May 2028)

Bachelor of Science in Physics (Honors, Distinction) **GPA: 4.36**

University of Texas at Austin Aug 2026 – Dec 2026 (Upcoming)

Exchange Semester, Department of Physics

SUMMARY

Year-2 physics undergraduate building toward research in complex systems and nonlinear dynamics. Hands-on experience across 15+ experiments spanning condensed matter, spectroscopy, plasma physics, biophysics, and ion-matter interactions. Computational modeling in Python, Julia, and MATLAB with focus on nonlinear dynamics and statistical methods. Seeking research opportunities that combine theoretical rigor with computational and experimental work.

PROJECTS

Physics Discovery: SINDy, Conservation Laws & Symbolic Regression Apr 2026

Self-directed · Julia, Python

- Implemented three complementary law-extraction methods on shared benchmarks: **SINDy** (STLSQ with sequential library expansion: polynomial → trigonometric → exponential) for ODE identification; **kernel conservation-law discovery** (RBF feature map, centered kernel matrix, minimum-eigenvalue generalized eigenproblem) for invariant extraction without knowing the functional form; **genetic-programming symbolic regression** for closed-form formula discovery
- Benchmarked on Van der Pol, pendulum, and Kepler orbit. SINDy achieves RMSE ≈ 0.001 on VdP recovery; kernel CLD extracts Hamiltonian invariants; GP rediscovers $T = 2\pi\sqrt{L/g}$ from (L, T) pairs alone; four-section interactive Pluto applet with per-part controls and live metrics

Causal Inference: Transfer Entropy, CCM & Causal Emergence Apr 2026

Self-directed · Julia, Python

- Quantified directional information flow using three **transfer entropy** estimators (histogram, KSG nearest-neighbour, symbolic/permutation entropy); applied **convergent cross-mapping** (CCM) via Takens delay-embedding to detect dynamical causation in coupled Lorenz and Rössler systems; computed **causal emergence** (ΔEI = EI_macro − EI_micro) across all 256 ECA rules under majority-vote coarse-graining
- Validated TE estimators against known coupling ε in coupled Hénon maps; showed CCM skill converges with library size only when causation is genuine; correlated emergent rules with Wolfram complexity classes; all three parts unified in a single Pluto applet

Coupled Oscillators: Synchronization, Networks & Chimera States Apr 2026

Self-directed · Julia, Python

- Simulated Kuramoto dynamics on all-to-all, Erdős–Rényi, and scale-free topologies; measured global order parameter r as a function of coupling K and extracted K_c analytically and numerically; extended to **Kuramoto-Sakaguchi** coupling to reproduce **chimera states** (coexisting synchronized and incoherent populations) with nonlocal connectivity parameter R
- Swept the (K, R) phase space for chimera stability; quantified chimera measure and local order parameter as a function of frequency disorder $\Delta\omega$; visualised through bifurcation diagrams, phase-circle animations, and space-time diagrams in a unified applet

Active Matter: Collective Motion & Single-Cell Swimming Apr 2026

Self-directed · Julia, Python

- Simulated the **Vicsek model** (N self-propelled particles, minimum-image PBC) sweeping noise η to measure order parameter $\varphi = |\langle e^{i\theta}\rangle|$ and locate the disorder-to-order **nonequilibrium phase transition**; independently simulated **run-and-tumble** particles (Poisson tumbling rate, constant speed, optional harmonic confinement)
- Measured ballistic-to-diffusive MSD crossover in run-and-tumble dynamics and validated the effective diffusion coefficient against analytic prediction; both models unified in a single Pluto applet with live particle animations and φ–η phase diagram

Quantum Wavepacket: Crank-Nicolson Schrödinger May 2026

Self-directed · Julia

- Evolved a Gaussian minimum-uncertainty wavepacket under the 1D TDSE via the **Crank-Nicolson** method (tridiagonal O(N) Thomas algorithm; unitary update; Gaussian absorbing boundaries at outer 5% of domain); implemented six interchangeable potentials (free, barrier, finite well, harmonic, double barrier, step) plus an arbitrary Julia expression entered at runtime
- Rendered ψ as a live **3D Argand helix** (pitch = de Broglie wavelength, shortening inside a well, becoming evanescent in a forbidden region) with simultaneous $|\psi|^2$ density panel; tracked norm, transmission/reflection coefficients, and center-of-mass in real time; interactive sliders for amplitude, width, and wavenumber

Spin Glass Physics of Neural Networks Apr 2026

Self-directed · Julia, Python

- Computed **diagonal Hessian spectrum** of a 2-layer MLP via finite-difference approximation at multiple training stages; tracked **inverse participation ratio** (IPR) of the leading eigenvector as a proxy for replica symmetry breaking, observing a glass-to-order transition signature as training progresses
- Connected Hessian flatness and IPR signatures to TAP/replica theory predictions for spin glasses; visualised evolving spectrum and parameter-space geometry through an interactive Pluto applet with live perturbation controls

Gray-Scott Reaction-Diffusion: Turing Patterns Apr 2026

Self-directed · Julia, Python

- Solved the **Gray-Scott** PDE system on a 200×200 grid with a finite-difference explicit scheme (5-point Laplacian); swept feed rate F and kill rate k to map the full **Pearson diagram** of pattern morphologies (spots, stripes, worms, solitons, labyrinthine, uniform)
- Identified second-order transition boundaries separating ordered patterns from trivial steady states; progressive animation reveals spatial pattern development in real time; Python replication includes bifurcation parameter scan

Physics-Constrained CD Spectral Inversion Apr 2026

Self-directed · Julia, Python

- Forward model predicts CD spectra from helix/sheet/coil fractions using reference basis spectra; **physics-informed MLP** inverts it with a loss penalising spectral reconstruction mismatch and simplex composition constraints (softmax output layer)
- Draws on hands-on CD spectroscopy experimental experience; validated on synthetic spectra across noise levels; the composition sum constraint reduces unphysical predictions by enforcing $\alpha + \beta + \mathsf{coil} = 1$ throughout training

Chaotic Dynamics of a Driven Quadruple Pendulum Jan 2026 – Apr 2026

Computational Methods in Physics (PC3236) · MATLAB/Python

- Derived Lagrangian equations of motion for four coupled pendulums with periodic driving torque
- Implemented custom **RK4 integrator** (validated against scipy RK45 to $< 10^{-6}$ rad over 20 s); produced **phase portraits**, **Poincaré sections**, and **bifurcation diagrams** showing onset of chaos

COURSEWORK

Experimental Physics I (PC2193):

- Measured **carrier type**, **density**, and **mobility** in n- and p-type germanium via the **Hall effect**; cross-validated mobility by independent **magnetoresistance analysis** ($R^2 > 0.99$); characterized the **extrinsic-to-intrinsic transition** at 106°C
- Determined **lattice constants** via **X-ray diffraction** using **Bragg's law**; achieved **sub-2% accuracy** for LiF and **0.24% deviation** for KBr identification through structural fingerprinting; extracted **Planck's constant** from bremsstrahlung cutoff analysis
- Calibrated **Helmholtz field constant** through five independent experimental methods with **3.3% uncertainty**; validated all **electromagnetic torque scaling laws** ($R^2 > 0.997$); corrected mathematical model using **quadratic fitting** ($T \propto d^2$ vs linear)
- Characterized **electron spin resonance** in paramagnetic systems; extracted **g-factors** from frequency–field data ($R^2 = 0.9995$); analyzed **Zeeman splitting** and resonance conditions
- Measured **Gaussian beam propagation**; determined **beam waist** and **Rayleigh range** with **sub-1% agreement** to theory; characterized **beam quality factor** ($R^2 > 0.998$)

Experimental Physics II (PC3193):

- Performed **X-ray fluorescence** spectroscopy for elemental identification and quantitative analysis of brass via **Gaussian deconvolution**; resolved the Cu K_β / Zn K_α overlap; estimated Cu/Zn/Pb mass fractions over five trials

- Indexed **Laue diffraction** patterns for a LiF single crystal; identified Si (diamond-cubic, $a = 5.430 \pm 0.002$ Å) and Mo (BCC, $a = 3.140 \pm 0.004$ Å) via **powder X-ray crystallography**; derived the 8-atom diamond-cubic structure factor
- Used **Raman spectroscopy** to characterize carbon allotropes (graphite, HOPG, nanotubes, diamond); estimated graphene layer count from 2D/G intensity ratios; identified an unknown wafer as crystalline Si from its 521 cm^{-1} mode
- Measured **Paschen curves** for air at three pressures; extracted the **second Townsend coefficient** ($\gamma = 0.0017 \pm 0.0003$); identified the transition from avalanche to streamer breakdown at high *pd*
- Ran **TRIM Monte Carlo simulations** of ion transport across six applied problems (nuclear microscopy, semiconductor implantation, sputtering, proton therapy); analyzed range, straggling, damage, and sputter yields

Biophysics II (PC3267):

- Monitored **protein unfolding** in BSA and lysozyme via **fluorescence spectroscopy** (280 nm excitation); observed a 24% intensity drop and 19 nm blue shift in BSA; correlated structural differences with disulfide-bond count
- Used **circular dichroism** to track secondary-structure loss under acid denaturation; BSA showed 21% ellipticity reduction versus less than 1% for lysozyme, consistent with lysozyme's four stabilizing disulfide bonds
- Imaged plant and animal cells via **fluorescence microscopy** with Hoechst nuclear staining; compared brightfield and epi-illumination contrast

Theory & Computation:

- **Mechanics:** Lagrangian and Hamiltonian formulations, coupled ODEs, variational principles, phase space dynamics
- **Electromagnetism:** Maxwell's equations, boundary-value problems, vector calculus, gauge theory
- **Quantum Mechanics:** Schrödinger equation, operator methods, eigenvalue problems, perturbation theory
- **Thermodynamics & Statistical Mechanics:** Entropy, Gibbs free energy, Boltzmann factor, equipartition, boson/fermion statistics, photon gases, Carnot engines
- **Mathematical Methods:** Linear algebra, ODEs/PDEs, Fourier analysis, complex analysis, special functions
- **Computation:** Python, Julia, MATLAB; numerical methods (Runge-Kutta, Newton-Raphson, Gaussian quadrature, Monte Carlo, finite differences); ODE/PDE solvers (wave, heat, Laplace, Schrödinger equations); data analysis, visualization
- **Artificial Intelligence:** Supervised learning (KNN, regression, neural networks), unsupervised learning (clustering), deep learning foundations, AI ethics
- **Biophysics:** Biomolecular electrostatics, reaction kinetics, self-assembly, molecular dynamics, protein structure prediction, motor proteins
- **Experimental Methods:** Statistical analysis, uncertainty propagation, calibration, regression, error budgets

RESEARCH INTERESTS

- **Complex Systems & Nonlinear Dynamics:** How deterministic rules produce effectively unpredictable behavior. Chaos theory, bifurcation analysis, and the geometry of attractors in phase space. Interested in systems where local interactions build global structure and the transition between ordered and chaotic regimes can be mapped and visualized.
- **Biophysics & Biological Complexity:** How physical principles govern biological systems at the molecular and cellular scale. Protein stability, conformational transitions, and the statistical mechanics of self-assembly. Drawn to problems where physical measurement (spectroscopy, diffraction, microscopy) makes biological mechanism legible.
- **Network Science & Information Theory:** How topology shapes dynamics. Information flow through network structures, feedback and robustness in coupled systems, and the connections between graph theory, statistical mechanics, and emergent collective behavior.
- **Computational Modeling & Geometric Visualization:** Building simulations that respect the mathematical structure of physical systems and using geometric tools (phase portraits, Poincaré sections, bifurcation diagrams) to make abstract dynamics concrete and interrogable. Bridging numerical methods with physical intuition.
- **Emergence & Statistical Reasoning:** The boundary between genuine collective phenomena and accumulated correlation. How macroscopic behavior arises from microscopic rules through statistical mechanics, and how to distinguish structure from noise in complex datasets. Interested in physics-informed machine learning as a tool at this boundary.

ACHIEVEMENTS

- **Silver Medal**, International Aerospace Olympiad 2024
- **JEE Mains: 99.14 percentile** (Top 1% of 1.47 million candidates)
- **JEE Advanced Rank: 9112**
- **IISER Aptitude Test Rank: 357**
- **BITSAT: 321/390**