Aaron James Lemmer

Adaptive + Fourier Optics · Wavefront Estimation + Control · Physics-based Modeling + Simulation · Hardware Prototyping

+1 (920) 410-0978 · aaron.lemmer@gmail.com · aaronlemmer.com · lemon8756 · aaronlemmer · @aaropress

"The true delight is in the finding out rather than in the knowing." —Isaac Asimov

Summary of Qualifications

Analytical Fourier-domain modeling and computational analysis of diffraction, beam propagation, wavefront aberrations in optical systems, far-field (Fraunhofer) and near-field (Fresnel) diffraction theory, linear systems theory, optimal control and estimation

Optics Imaging systems, spatial filtering (e.g. apodization, stellar coronagraphy, and phase-contrast imaging), wavefront modulation, interferometry, surface metrology, wavefront sensing, closed-loop wavefront estimation and control, deformable mirror design, testbed layout, beam collimation and alignment, optical tweezers, lasers, ISO 5–7 (Class 100–10,000) cleanroom procedures

Electronics Hardware prototyping, mixed-signal design (D/A and A/D conversion), logic design, data acquisition, FPGAs, troubleshooting, calibration, unit testing, inductive load drivers, pulse-width modulation, I2C serial interface, ESD-safe environments

Software MATLAB, LabVIEW, Mathematica, LaTeX, COMSOL Multiphysics, PTC Creo, C, git

Education

Princeton University — *Princeton, NJ*

PhD Candidate – Mechanical and Aerospace Engineering (MAE) — *Expected 2021*

MA – Mechanical and Aerospace Engineering — *April 2014*

- Major Emphases: Applied Physics, Optics + Lasers, Dynamics + Control
- Thesis: *A Ferrofluid Deformable Mirror for Adaptive Optics*

University of Wisconsin—River Falls — *River Falls, WI*

BSc – Applied Physics, Mathematics — *May 2010*

- Summa Cum Laude, Honors Program, Dean's List (all semesters)
- Thesis: *Construction of a diode-pumped Nd:YVO_4 laser with Cr:YAG passive Q-switching and intracavity frequency doubling*
- Honors: *Implementing the fast Fourier transform on a FPGA with a COordinate Rotational DIgital Computer (CORDIC) module*

Research + Development

High-Contrast Imaging Lab, Princeton University — *Princeton, NJ*

Ferrofluid Deformable Mirror for Adaptive Optics — *2013 – 2020*

We work intimately with NASA to engineer technologies that enable satellites and ground-based telescopes to directly image Earth-like planets orbiting nearby stars. Our projects span technology readiness levels (TRL) 1–7, including the coronagraph for the Roman Space Telescope. Our core competency is the application of frequency-domain reasoning and closed-loop feedback to the synthesis of optimized optical imaging systems; our primary techniques include shaped-pupil coronagraphy, spatial wavefront modulation, and optimal wavefront estimation and control.

- **PhD in a Nutshell** Deformable mirrors (DMs) mitigate aberrations by modulating the wavefront in a closed-loop adaptive optics system. I studied an idea for a new ferrofluid-based DM device architecture, cultivating the infant concept into several working prototypes, mathematical models for analysis and control, a deep grasp of the fundamental limitations and capabilities of the device, and a roadmap toward improved performance.
- **Mathematical Modeling + Simulation**
  - Used Fourier optics to simulate wavefront propagation (electric field amplitude and phase) in a coherently illuminated optical system
  - Engineered and simulated pupil-plane and focal-plane mask designs in MATLAB to (1) strategically shape point-spread functions (PSFs) for enhanced image quality and (2) optimize the signals of targeted aberration modes for improved wavefront sensor performance
  - Derived a multiphysics model of the ferrofluid deformable mirror from first principles that captures its coupled nonlinear characteristics
  - Used analytical model reduction and linearization by asymptotic and perturbation techniques to probe steady-state and dynamic behavior
  - Investigated underlying physics of a deformable mirror to inform prototype development and predict device and system-level performance
  - Devised a novel mathematical framework for parameterizing the design of any new deformable mirror in order to optimize the closed-loop imaging performance of its parent adaptive optics system (e.g., maximum image contrast)
- **Optical Metrology + Prototyping**
  - Built a custom Fizeau interferometer to measure the topography of a proof-of-principle deformable mirror prototype
  - Coded Fourier transform phase demodulation and 2D phase unwrapping algorithms (known as Fourier fringe analysis, or FFA) in MATLAB to convert single-frame images of interference fringes into topographical surface measurements of an optical element
  - Simulated the impact of high-finesse and nonparallel optical cavities as sources of error/uncertainty in the performance of FFA (since the ferrofluid deformable mirror can introduce these non-standard conditions) and found significant limitations; this discovery precluded the purchase of the gold-standard commercial metrology solution, and saved us $70k when we opted for an alternative, emerging technology
  - Designed and constructed an optical testbed to measure and verify the performance of a prototype deformable mirror
  - Experienced with wavefront sensor (WFS) technologies, including the Shack–Hartmann WFS and four-wave lateral shearing interferometer

- **Electronics Development + Testing**
  The deformable mirror concept features a thin flexible reflective surface supported by a pool of ferrofluid. An integrated array of current-driven electromagnets generates forces within the ferrofluid that result in controllable deformations of the mirror. I fully developed and tested an electronics package in house, including the accompanying software application and LabVIEW user interface, to configure and manage the electric current in the individual coils and control the magnetic influence on the mirror. At the outset, we had no electronics lab space or equipment, so I constructed an ESD-safe workspace from the ground up and furnished it with tools and diagnostic equipment. The entire project was completed in under 12 months, and included training an undergraduate mechanical engineering intern to help prototype, test, and troubleshoot electronics (see mentorship experience below).
  - Full life-cycle development from requirement definition stage through schematic design, breadboard prototyping, system-level integration of electronic subsystems, testing and validation, and PCBA (printed circuit board assembly) layout and fabrication
  - Created and implemented hardware testing strategies for digital, analog, and mixed-signal systems, from single ICs to fully-functional assembled PCBAs using diagnostic equipment including DMMs, oscilloscopes, and logic analyzers
  - Engineered an electronics solution for the ferrofluid deformable mirror that operates on an off-the-shelf 100 W power adapter to deliver low-voltage, high-current analog signals to an array of electromagnets; the design is fully scalable to over 100 actuators
  - Exposed to multi-layer PCBA layout, 6 months experience working with PCB designers and fabricators, including design reviews

National Science Foundation REU, Michigan State University

East Lansing, MI

Optical Tweezers — *Summer 2009*

Searched for dipole interactions and self-organizing dynamic behavior of optically trapped microscopic particles in a colloidal suspension.

- Constructed a custom laser microscope with an optical tweezers capable of 3D trapping and manipulation of microspheres in an aqueous solution
- Assembled an illumination system and calibrated a pattern recognition software to enable tracking of the individual spheres
- Applied my previous research experience at UW–River Falls, which focused on the dynamics of an aerosol droplet optically trapped in air
- Diagnosed a quality control problem with a commercial fast-steering mirror; provided detailed test data to vendor to improve product design

Undergraduate Research Fellowship, Mayo Clinic College of Medicine

Rochester, MN

Computerized Tomography Clinical Innovation Center — *Summer 2008*

The CT Clinical Innovation Center works with industry partners and leverages patient data to develop and evaluate new computerized tomography (CT) imaging technologies, methods for quantifying disease progression and organ function, and techniques for reducing radiation doses.

- Designed and built a device to generate synchronized motion artifacts with humanoid models for CT imaging studies
- Evaluated competing optically-stimulated luminescent dosimeters for CT machine calibration

Publications

1. Lemmer A.J., Griffiths I.M., Groff T.D., Rousing A.W., and Kasdin, N.J. *Mathematical and computational modeling of a ferrofluid deformable mirror for high-contrast imaging,* Proc. SPIE 9912 (2016).
2. Groff T.D., Lemmer A.J., and Riggs, A.J.E. *A new deformable mirror architecture for coronagraphic instrumentation,* Proc. SPIE 9904 (2016).
3. Lemmer A.J., Groff T.D., Kasdin N.J., Echeverri D., and Cleff I.R. *Technological progress of a ferrofluid deformable mirror with tunable nominal optical power for high-contrast imaging,* Proc. SPIE 9605 (2015).

Teaching + Mentorship

Brightmont Academy

Redmond, WA

Full-time Honors STEM Instructor: Mathematics · Physics · Chemistry · Biology · Environmental Science · Honors · AP — *2018 – 2021*

Brightmont Academy is a private school that specializes in a one-on-one instructional approach that is geared to provide individualized attention to students with special needs, including autism, learning disabilities, emotional impairments (e.g. anxiety, depression), and/or academic gifts.

- Create lesson plans and activities that match the unique learning styles, interests, imaginations, and abilities of individual students in grades 6–12
- Developed custom university-level curriculum for gifted students, including special topics in mathematics and advanced science lab activities
- Assess student skills and degree of mastery to determine individual needs and, where necessary, modify course curricula and activities to comply with individualized education plans (IEPs)
- Provide a safe, supportive, and adaptive student-centered learning environment for students with diverse social, mental, and emotional needs
- Manage student behavior while developing and teaching behavioral strategies that support his/her/their emotional and behavioral self-regulation and executive functioning skills
- Promote active and metacognitive learning processes through inquiry-based discussion and a project-based approach
- Built out, upgraded, and managed the shared campus science lab space; developed and implemented a comprehensive lab safety policy

Yu's Elite Education

Plainsboro, NJ

Mathematics Instructor — *2014 – 2017*

Yu's Elite is a family-owned education center with three campuses, offering extracurricular competition prep and accelerated enrichment courses in math, science, and language arts for gifted K–12 students. I was recruited to teach math in private (1–2 students) and group (4–10 students) settings.

- Generated all curriculum, lesson plans, and homework to appropriately challenge each group of students, ranging from 4th- to 10th-grade level
- In 2016–2017, five Yu's Elite students earned perfect AMC8 scores, 33 qualified for the 2017 American Invitational Math Exam, and nine qualified for either the 2017 USA Junior Math Olympiad or USA Math Olympiad

High-Contrast Imaging Lab, Princeton University

Princeton, NJ

Research Mentor for Undergraduates and Visiting Scholars — *2013 – 2017*

- Coordinated immersive summer internship and academic-year work experience for 4 undergraduate engineers and advised experimental work and writing for 3 senior thesis projects
- One undergraduate worked with me for three academic years, including two summers and his senior thesis. We worked side by side to develop the electronics package described above. In the process, I taught him analog electronics and digital logic design, as well as hands-on laboratory techniques including LabVIEW; electronics prototyping, calibration, test, and fabrication in an ESD-safe environment; ray and wave optics; optical prototyping, alignment, and collimation in a semi-clean environment. By the time the design was ready for layout on a PCB, we were contributing to the project as peers and stimulating each other's contributions.
- Evangelized best practices, including organization and documentation, to ensure testable, scalable, and quality prototypes were being developed

McGraw Center for Teaching and Learning, Princeton University

Princeton, NJ

Pedagogical Training, McGraw Teaching Seminar — *2015 – 2016*

The McGraw Center prepares grad students and faculty for roles as mentors and educators by providing a collaborative environment to engage with contemporary research on teaching and learning. I was selected and awarded a stipend to participate along with 28 colleagues from both scientific and humanitarian disciplines. Topics included, for example, creating inclusive classroom environments, techniques for generating inquiry-based discussion, and approaches for defining and executing one's own teaching practices and assessing their effectiveness.

Assistant in Instruction, MAE Department, Princeton University

Princeton, NJ

Intro. to Engineering, Math, and Physics · Aircraft Flight Dynamics · Space Systems Design · Thermodynamics — *2011 – 2015*

My experience was a little deeper than the typical grading, holding office hours, and organizing and teaching weekly precept lectures:

- Taught the lab portion of the freshman engineering survey course twice, and mentored 3 graduate students in teaching it in subsequent years; designed, taught, and troubleshot lab activities for the robotics unit (students built and programmed autonomous path-following LEGO vehicles)
- Nominated for a monetary departmental teaching prize for Aircraft Flight Dynamics, a MATLAB-heavy course in which students simulated the flight characteristics and control of a Cessna business jet; I took on this subject for passion's sake, teaching myself the material on the fly

Society of Physics Students, UW–River Falls Chapter

River Falls, WI

Youth STEM outreach, various roles — *2006–2010*

The Society of Physics Students fosters active scientific citizenship by providing leadership experience, opportunities to present scholarly work in professional meetings and journals, access to undergraduate research experiences, and educational outreach services to the local community. The UW–River Falls chapter has an award-winning pedigree of national excellence for its level of participation, engagement in the local community, and support for national initiatives.

- Performed educational physics demonstrations in local middle and high school classrooms, and hosted inner-city students from the Twin Cities to the UW–River Falls campus for the same
- Founded and organized the annual Halloween Haunted Lab event, an educational event operated jointly with undergraduate chemistry students on campus for elementary-aged kids featuring themed physics and chemistry demonstrations
- Helped organize chapter participation in outreach events, including Super Science Saturday at 3M in St. Paul, MN (a STEM event for children of 3M employees) and staffing and judging Science Olympiad competitions
- Tutored introductory-level physics students as a volunteer in the after-hours help room

Volunteer Educational Outreach

July 2014	**Lab Instructor**, Carl Sagan Summer Workshop, NASA Exoplanet Science Institute + CalTech	*Pasadena, CA*
August 2013	**Lab Instructor**, International Summer School on Adaptive Optics, UC–Santa Cruz	*Santa Cruz, CA*
2009–2010	**Organizer and Instructor**, 1st and 2nd Annual Physics Days with the Minnesota Twins	*Minneapolis, MN*
2009–2010	**President**, Society of Physics Students, UW–River Falls Chapter	*River Falls, WI*
2008–2009	**Vice President**, Society of Physics Students, UW–River Falls Chapter	*River Falls, WI*
2007–2008	**Vice President**, Student Board, St. Croix Valley Symphony Orchestra	*River Falls, WI*

Honors + Awards

2015–2016	**Selected Participant**, McGraw Center Teaching Seminar, Princeton University (see above)
2014	**2nd Place**, Mechanical and Aerospace Engineering Research Day, Princeton University
2011	**Honorable Mention**, NSF Graduate Research Fellowship Program
2010	**Recipient**, Mechanical and Aerospace Engineering Merit Prize, Princeton University
2006–2010	**Recipient**, UW—River Falls Physics Alumni Scholarship
2006–2010	**Recipient**, Robert A. Kotecki Wisconsin Academic Excellence Scholarship
2009	**Recipient**, Dr. Henry Tranmal Memorial Scholarship, for excellence in physics
2006–2008	**Recipient**, Marcel K. Lynum Foundation Scholarship, for academics and leadership
2008	**Inducted**, Sigma Pi Sigma Physics Honors Society
2008	**Recipient**, Curt and Dee Larson Scholarship, for excellence in physics
2007	**Recipient**, Dean Neal Prochnow Scholarship, for freshman academics