R. E. HOPKINS CENTER NEWSLETTER

THE UNIVERSITY OF ROCHESTER'S EDMUND A. HAJIM SCHOOL OF ENGINEERING AND APPLIED SCIENCES

FALL 2014

FROM THE DIRECTOR

Jannick Rolland, Director

From the Director

Greetings! Among the growing activities of the R. E. Hopkins Center for Design and Optical Engineering, we would like to introduce you to the new staff of the center. As we focused this past year on growing the center's educational activities and creating synergy with the newly formed NSF I/UCRC Center for Freeform Optics (CeFO), we will take the opportunity to highlight new funding sources and associated educational projects engaging undergraduate students in hands-on research projects. This newsletter features an article with coauthor Isaac Trumper (senior) on the testing of Zernike freeform optical surfaces, an article by Jessica DeGroote Nelson on a collaborative undergraduate class project conducted in the Hopkins Center, and alumnus Joseph Howard (MS '97, PhD '00) shares his career path with us.

Martin Huarte-Espinosa

Technical Staff

Farewell to Martin Huarte-Espinosa, who worked with the R. E. Hopkins Center from March 2013 to July 2014 and accepted a position as High Performance Computing Specialist at the Center for Advanced Computing & Data Systems at the University of Houston in Texas. Huarte-Espinosa conducted research in computational methods for freeform optics and helped coordinate some of the daily activities of the R. E. Hopkins Center. He made significant contributions to our programs and will be missed.

Welcome to Adam Hayes, who joined the Institute of Optics in August 2014. Hayes received his PhD in nuclear physics in 2005 from the University of Rochester. In synergy with the R. E. Hopkins Center, Hayes is focusing on the development of a computational research platform for freeform optics combined with 3D visualization. This project is supported by the Department of Energy (DOE) as part of a three-year federal grant (PI: Jannick Rolland) in the total amount of $350,000 awarded January 1, 2013, which helps support

Adam Hayes

the mission of educating students in optics manufacturing. Other faculty collaborators on this project include Miguel Alonso and Jon Petrucelli (PhD '10), assistant professor at SUNY University at Albany, who together investigate high-speed computational models of light fields propagation in optical systems, called "Dressed Rays." Hayes is also collaborating with Daniel Nikolov and Robert Gray, second-year and fourth-year PhD candidates at the Institute of Optics, respectively; both are involved in the DOE project and assisting in mentoring undergraduate students engaged in the R. E. Hopkins Center. Finally, Hayes will help coordinate tours of the center for some of our visitors and prospective students.

New Funding and Associated Activities

This year the center received a grant from the Optical Society of America (OSA) Foundation in the amount of $17,200. This grant supported educational hands-on activities in the center over the summer for two international students of underrepresented countries in optics as well as one equivalent undergraduate student from the University of Rochester. This grant fell under the mission of the OSA and its Foundation Global Outreach.

Over the summer as part of this OSA Foundation Initiative, we hosted Eric Dongmo of Yaoundé University in Cameroon, who inspected manufactured lenses with, for the first time, a Zygo Fizeau phase shifting interferometer, a Zygo NewView™ broadband interferometer, and an AudioDev coating measurement system. Dongmo, mentored by second-year graduate student Eric Schiesser, also learned about MTF measurements with the new Optikos MTF bench that was placed in the center this summer. We also hosted Pornthep Pongchalee (Racha) of Suranaree University of Technology in Thailand, who focused his interest on building a fiber-optics broadband interferometer combining hardware and LabView programming. Mentored by fifth-year graduate student Jianing Yao, Pongchalee explored probing the elastic properties of materials with light fields. Dongmo and Pongchalee presented their summer research as a poster at the August 2014 undergraduate research event at the University of Rochester.

Dongmo and Pongchalee, in addition to fully engaging in learning optics hands on, had the opportunity to discuss OSA student activities with other students and bring back their experiences to their respective OSA student chapters in Cameroon and Thailand, respectively. One of the most admirable things is to witness how the OSA Foundation's vision to build bridges among its student chapters across the world was made possible with volunteers in the R. E. Hopkins Center and the generous support of the OSA Foundation.

Undergraduate students at the Institute of Optics who have benefited from support from the OSA Foundation and the R. E. Hopkins Center combined include Trevor Ivanov (senior), Isaac Trumper (senior), and Ziriu Zhang (sophomore). Ivanov started working in the R. E. Hopkins Center as a junior in spring 2014 and is learning about metrology, including freeform optics. Isaac Trumper, who started working in the R. E. Hopkins Center as a sophomore, participated in research for the fabrication and testing of freeform plates (see article in this issue), a project Trumper currently pursues as independent research. The plates are being tested in a custom designed and built Schmidt telescope coupled to a Zygo Fizeau interferometer, both located in the R. E. Hopkins Center. Ziriu Zang (sophomore) and Brandon Dube (freshman) joined in the project with Trumper this fall 2014 to develop skills in hands-on optical fabrication and metrology. Students engaging early in their studies in the R. E. Hopkins Center often become mentors themselves, in various educational activities. Trumper, for example, is now a teaching assistant for Optics 243, a class on optical manufacturing for undergraduate students, taught this fall by Jessica DeGroote Nelson, manager of R&D at Optimax Systems Inc. Trumper is also a mentor to other more-junior undergraduate students motivated to learn optical metrology and fabrication hands-on in the R. E. Hopkins Center.

From left to right: Pornthep Pongchalee (Racha) and Eric Dongmo (OSA Foundation Fellows) enjoy a bike ride with University of Rochester students Emily Windes, physics and mathematics, and Daniel Van Hoesen, summer REU student in physics.

From left to right: Eric Schiesser and Eric Dongmo

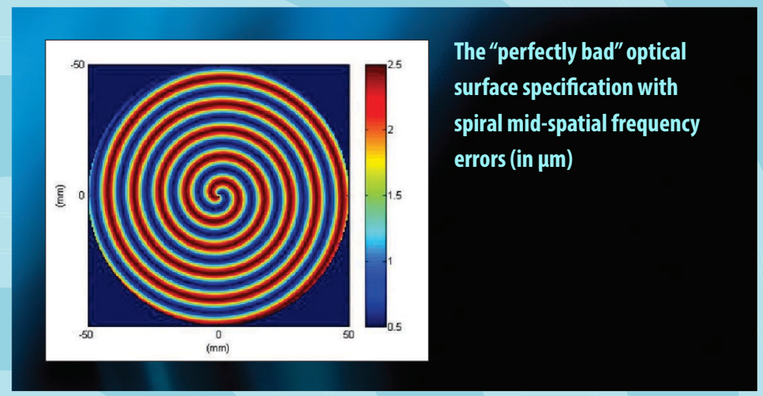
"At my first meeting with Eric Schiesser [a second-year PhD student at the Institute of Optics who volunteered his time in the R. E. Hopkins Center summer 2014], he told me 'don't care if you don't have a big background in optics, at the end of this summer, you will be great.' I hope that I am. My dream was always to do optics; when I had the opportunity, I gave the best of me."
— Eric Dongmo

From left to right: Mickael Angelo (Brazil), Eric Dongmo (Cameroon), and Racha (Thailand) celebrate new friendships during their summer abroad at the University of Rochester.

Optical Designers and Fabricators Join Forces to Teach 'Co-opetition' to Next Generation

A joint collaboration between the University of Rochester, the University of Arizona, and Optimax

"Co-opetition" is a catchphrase in the Rochester, N.Y.–area optics cluster. It's a saying with no exact definition, but it has a meaning amongst the industry to work together for the greater good of the optics business and local economy. It is because of this spirit of collaboration that this past spring a joint effort among two professors, one CEO, and a class of young optics students began.



The "perfectly bad" optical surface specification with spiral mid-spatial frequency errors (in µm)

It all started when research professor and principal scientist Dae Wook Kim, University of Arizona, College of Optical Sciences, had a curiosity for a surface with a prescribed surface error, sometimes referred to as a "perfectly bad" surface. Optimax's annual in-kind five-thousand-dollar research grant was extended to Kim for providing blanks for an optical component project that helps develop technology and solve industrial problems. Kim says his interest was "to develop a para-metric smoothing model for visco-elastic non-Newtonian fluid polishing tools."

Jessica DeGroote Nelson (PhD '07, MBA '13)

Jessica DeGroote Nelson, a PhD alumnus of the Institute of Optics in Rochester and currently head of research and development at Optimax began developing the project in her role as adjunct professor for an undergraduate course (Optics 243) on optical fabrication she has offered every other year since 2010 in the R. E. Hopkins Center at the University of Rochester. Although this type of job is routine for Optimax, it was Nelson's connection to the University of Rochester that led to the opportunity for undergraduate student involvement. "It seemed like a natural fit and a great opportunity to have the students in Optics 243: Optical Materials, Fabrication, and Testing create and build the optics," says Nelson.

This was a true collaboration among Rochester, Arizona, and Optimax, as Optimax opticians were able to provide the polished spherical substrates, and the students were tasked with working directly with Professor Kim to fulfill the project requirements for creating the optical surfaces. With the resources available at the R. E. Hopkins Center on the University of Rochester campus, students were able to use the QED Q22-XE Magnetorheological Finishing (MRF) platform and the Zygo Fizeau Interferometer to successfully complete the project.

The MRF process is a highly deterministic method for polishing the surface of an optic. Unlike most other polishing processes, the CNC-controlled MRF machine does not know about "good" or "bad." It is programmed by an operator to follow a set of instructions that move the part through a ribbon of magnetically stiffened polishing slurry. The undergraduate students were instructed to do something that few other opticians or optical engineers would contemplate, and that was to purposefully alter a smooth surface and create a textured one (see figure). Professor Kim at Arizona wanted to use this textured surface in further studies of how conventional polishing processes can be made to remove them using theoretical models of removal.

"Students were able to learn firsthand the importance of technical communication and how to specify optical designs for manufacturing," says Rick Plympton, CEO of Optimax. "They also were able to experience the challenges associated with optical fabrication and testing, which is something we deal with every day."

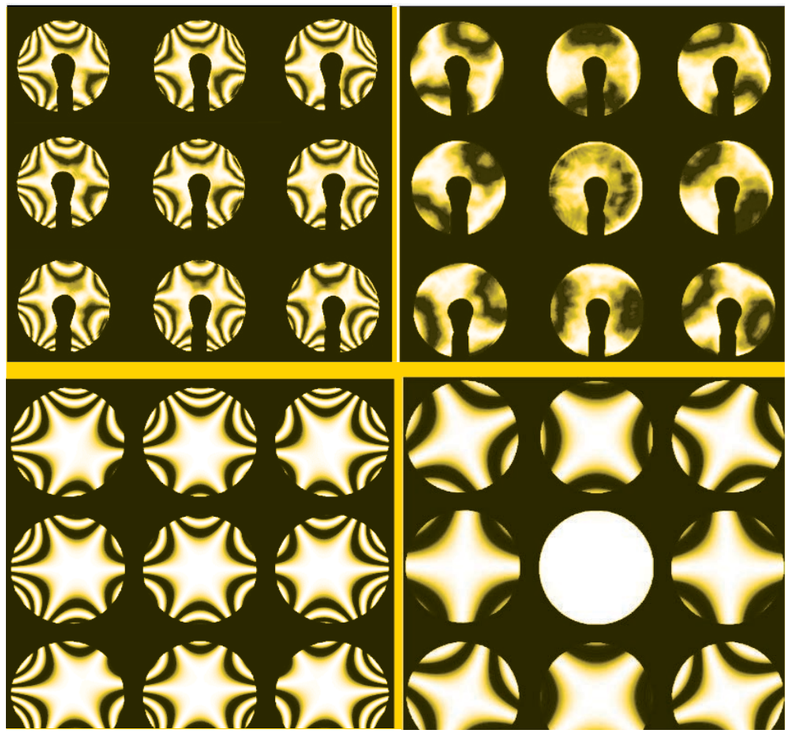
Making Freeform Optics in the R. E. Hopkins Center

Kyle Fuerschbach, Isaac Trumper, Edward A. LaVilla, Kevin P. Thompson, and Jannick P. Rolland

Freeform optical surfaces are creating exciting new opportunities across the industries of mathematics, mechanics, and optics for design, fabrication, assembly, and testing applications

We acknowledge support from the II-VI Foundation whose mission is *"To encourage and enable students to pursue a career in engineering, science, and mathematics while maintaining a standard of excellence in that pursuit."*

Freeform optical surfaces are creating exciting new opportunities across the industries of mathematics, mechanics, and optics for design, fabrication, assembly, and testing applications [1-2]. In optical design, an active area of research is how to effectively optimize the shape of a freeform surface when our basic understanding of aberration theory has been limited for 150 years to rotationally symmetric systems. A foundation for understanding how the aberration fields evolve when symmetry no longer exists is nodal aberration theory (NAT). The theory, discovered by Shack [3] and developed by Thompson [4], describes the aberration fields of optical systems when the constraint of rotational symmetry is no longer imposed. Until recently, NAT was limited to optical imaging systems made of rotationally symmetric components that are tilted and/or decentered. Fuerschbach et al. extended NAT to predict the aberration behavior of a class of freeform surfaces called φ polynomials [5-6]. One common set of φ polynomials that is routinely used to fit deformations of optical surfaces in optical testing is the Zernike polynomial set.

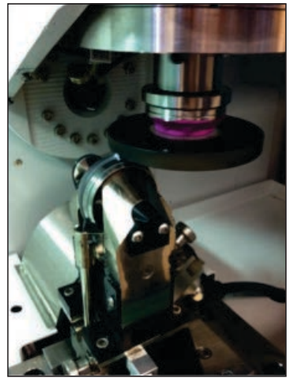


Shown in Figure 1 (top left) is a three-by-three grid of the measured wavefronts. The Zernike trefoil was subtracted in the interferograms shown to the right. Note that the field conjugate dependence of the astigmatism generated by Zernike trefoil is clearly seen in this figure. The expected full-field displays for trefoil (also known as elliptical coma) and astigmatism are shown in the lower part of the figure, respectively. The data obtained from the experiment confirm the theoretical predictions of nodal aberration theory (NAT).

A recent experiment conducted in the Robert E. Hopkins Center aimed to validate the theoretical predictions of NAT for freeform surfaces. In the experiment conceived, an aberration-generating telescope was built. The nominal telescope is a Schmidt design that consists of a spherical primary with an aspheric corrector plate. The aperture stop and corrector plate are collocated at the center of curvature of the primary mirror so the system is corrected for all third-order aberrations. A freeform optical plate is inserted in the optical path, at the aperture or away from the aperture, imparting unique aberration-fields dependence into the telescope wavefront.

For this experiment, Fringe Zernike trefoil was polished into the surface of a glass window using a sub-aperture polishing technique called magnetorheological finishing (MRF) available on our Q22 polishing equipment from QED technologies. The aspheric corrector plate was also fabricated using MRF because the aspheric was not commercially available. MRF uses a ferrofluid embedded with a polishing agent to deterministically remove material from a small section of the full aperture at a point in time. The corrector plate has a peak-to-valley (PV) of 26.6 μm departure from planar, where the Zernike Fringe trefoil plate has a PV of 5.75 μm.

The surfaces created in the R. E. Hopkins Center to be inserted in the Schmidt telescope are a prime example of the potential uses for the center. Their making included the design of an optical system, fabrication and testing of key components, and, finally, experimentation using the very optics that were made. With the vast applications in aberration research for the Schmidt telescope, the fabrication of new Zernike and other freeform surfaces are already in the conception stage. Along with the creation of new windows comes their optical testing. This is done primarily using a Fizeau phase shifting laser interferometer from Zygo corporation provided to the R. E. Hopkins Center. In the experiment using the Zernike Fringe trefoil plate, the surfaces were tested throughout the fabrication process to ensure quality control.



With the use of the Zygo interferometer, we measured the wavefront produced by the Schmidt telescope across the field of view of the telescope. In order to properly study the aberrations, the field of view (FOV) of the telescope was scanned in both the vertical and horizontal directions with 81 grid points, accurately characterizing the field dependence of Zernike trefoil. Shown in Figure 1 (top left) is a three-by-three grid of the measured wavefronts. The Zernike trefoil was subtracted in the interferograms shown in Figure 1 (top right). Note that the field conjugate dependence of the astigmatism generated by Zernike trefoil is clearly seen in that figure. The expected full field displays for Trefoil (also known as elliptical coma) and astigmatism are shown in the lower parts of Figure 1, respectively. The data obtained from the experiment confirms the theoretical predictions of NAT.

The Fringe Zernike trefoil is just one example of an aberration that is interesting to study; many others are on the way to be explored. With a better understanding of the field dependence of the aberrations validated through experimentation, a new family of optical designs in 3D package geometries can be further implemented in optical systems.

The topics associated with the utilization of this telescope range from fabrication and testing of optical surfaces to the study of a specific aberration's behavior as a function of field. Further testing with this telescope will continue to involve undergraduate students, providing them with an opportunity to experience optical testing and fabrication and integrate knowledge acquired through their classes.

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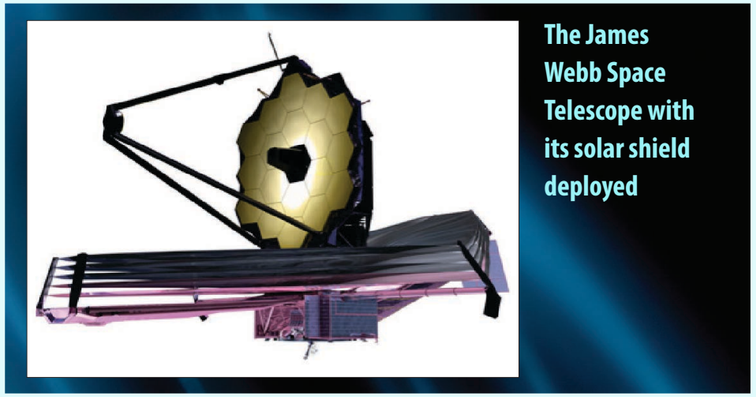
" I was fortunate as an undergraduate student to be involved in projects that are on the forefront of research and to be fully included in the entire creative and discovery process."
—Isaac Trumper

‘Have you traced a ray today?’


Joseph M. Howard (MS ’97, PhD ’00)

“Have you traced a ray today?” This quote is posted in bold letters on my door at work, reminding me each day when I arrive to keep exercising the fundamentals, especially when time pressures from managers and customers interfere with any attempt at keeping a daily routine. Taken literally, one might think I’m suggesting the use of a slide rule or some other hand calculation to brute force the geometric trajectory of light through an optical system. But the reminder to me is a more general suggestion to practice the fundamentals, to not forget the basics of my profession, and to remember where I started my career as an optical engineer.


The James Webb Space Telescope with its solar shield deployed

Choose happy. I first visited the Institute of Optics as a “prospective” PhD student in April of 1994, just after finishing a several-month deployment to the Caribbean on the USS *Hammerhead,* where I was completing my service as a submarine officer in the Navy. It was an eye-opener to fly in from the blooming azaleas of southern Virginia to the eight-inch deep snow of Rochester, but the weekend visit was unforgettable to me because the optics students in Rochester were happy. This was either due to the generous funding of the various receptions held for the prospective students or more likely due to what I observed at the time from visiting several universities: optics graduates were finding greatest success when it came to job placement. This fact was enough persuasion for me to “choose light,” so I found myself in the dark winters for the next five years on the northern shore of the United States. I chose to concentrate on optical design of reflective systems . . . and I loved it. Geometrical optics is one of the first courses we take at the institute, and it is arguably the most used after graduation. Sooner or later, no matter what our optics specialty, most of us will end up tracing rays at some point in our career.

Work happy. Since graduating, I have relocated to Washington, D.C., to work for the federal government but as an optical engineer for a much smaller agency than the Navy. Like my choice for graduate school, I selected my new employer, NASA, because the people there were happy, and the agency generally had a reputation for very high morale . . . and there are quite a few other alumni here! Since joining in 1999, I’ve been primarily working on the James Webb Space Telescope (JWST) project, the successor to the Hubble Space Telescope, where I’ve contributed optical design and analysis to a large team of multidisciplinary engineers working to make the largest space-based astronomical observatory ever. Space-flight projects take time to design, integrate, and test, and when this telescope launches in 2018, I will have worked for a full 20 years on this one alone—about half a career! While the pace appears slow, the layers of details are significant, so there’s always something new to learn.

Reach out. While JWST dominates my time, I make the effort to keep balanced professionally by contributing to our broader optical engineering community through volunteering to societies such as OSA and SPIE by presenting at conferences, peer-reviewing papers, and participating in committee work. These efforts keep me connected to my peers and help prevent me from intellectual stagnation. I also greatly enjoy mentoring interns and co-op students that I’ve recruited from The Institute of Optics, often with the help and recommendations from my former colleagues and friends still in Rochester. I’ve even been successful at helping get a few of them hired here at NASA.

Finally, I’ve been fortunate to be able to teach a course in optical design to students pursuing an applied physics master’s degree at a local university (Johns Hopkins) and would highly recommend the experience. I have heard it said—and now through experience believe—that you don’t truly know a subject until you attempt to teach it. One of the first assignments I give the students is to send me a photo with the following reminder posted next to their workstation: **“Have you traced a ray today?”**

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Please visit our website that is located at www.hopkinscenter.rochester.edu/ to encompass a large audience across optics manufacturing. We encourage your corporation or institute to link to us through your website to help our outreach. We are working toward connecting a strong and dedicated community of scientists that recognizes optics as a core technology of the 21st century and whose deepest values include excellence in optics education. At a time when support to research and education is diving, together let’s surf the waves we can afford to maintain focus on our future.

HOPKINS NEWS

The National Science Foundation also supports research for U.S. citizen undergraduate students through its Research Experiences for Undergraduates (REU) program. At the Institute of Optics, NSF REU awardees who leverage resources in the R. E. Hopkins Center include Rebecca Pettenski (senior), who is working on optical metrology for freeform optics, and Natalie Pastuszka (senior), who is working on terahertz research.

The launch of CeFO on August 1, 2013, also created the additional opportunity to secure two additional REU fellowships for two U.S. citizen undergraduate students at the University: Nick Cirucci (senior) is an awardee from the Institute of Optics working on freeform optics metrology, and Alexandra Taylor (junior) is an awardee from mechanical engineering working on additive printing of optical components.

Another great piece of news is that the Hilbert family—Angela, Daniel, and David—donated $10,000 towards the continuation of the Robert. S. Hilbert Telescope project we featured in the Fall 2012 issue. We will keep you informed about exciting new developments by students of the telescope in future issues. Also in 2014, the center received $20,000 from the Institute of Optics to support the overall educational undergraduate activities of the center. Finally, two faculty members donated $10,000 from their discretionary funds towards overall support of activities in the center.

We seek partnerships with industry in educating a next-generation workforce in optical engineering and science that is central to the educational mission of the R. E. Hopkins Center. Industry may engage with the center in supporting a specific student on a research project. Your industry may assist in mentoring for one semester, the entire academic year, or the summer or engaging on a class project such as Senior Design.

Please visit our website at www.rochester.edu/HopkinsCenter. We encourage your corporation or institute to link to us through your website to help our outreach to a next generation of optical engineers.

The industrial board of the NSF I/UCRC Center for Freeform Optics (CeFO) gathered on Nov. 6 and 7 in Rochester, N.Y., with the faculty and students of CeFO to review the center’s advancement in research and advise on the growing research portfolio of the center. In-depth roadmaps for freeform optics are also being uniquely developed. We thank the Air Force Research Laboratory, ARRI, Ball Aerospace, OptiPro, Perkin Elmer, PolymerPlus, Rochester Precision Optics, Schott, and Zygo for their support in 2014.

“The Center for Freeform Optics (CeFO) not only creates bridges between academia, industry, and government for educating our next generation engineers but also creates synergy with undergraduate education by guiding innovative research in the R. E. Hopkins Center.”
— Jannick Rolland

Robert E. Hopkins Center for Optical Design & Engineering

DESIGN • BUILD • ANALYZE • TEST

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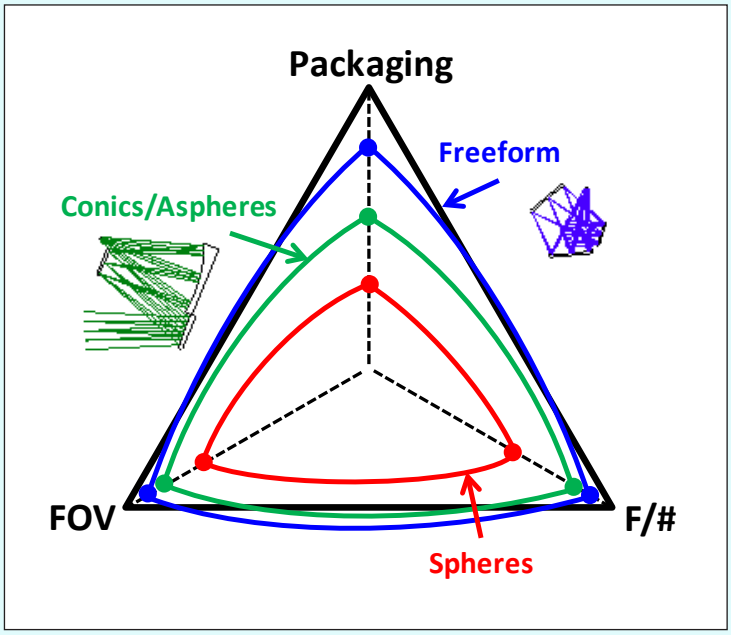

Students engaged in the R. E. Hopkins Center benefited in 2014 from support of the OSA Foundation, the II-VI Foundation, and the National Science Foundation, as well as contributions from the endowed chair professors at the Institute of Optics.

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