Science AMA Series: I'm Dr. Dae Wook Kim, and we are the Large Optics Fabrication and Testing (LOFT) Group at the College of Optical Sciences. We want to share our knowledge about the tools required to make and then test the world's largest mirrors! AMA!

LOFT$_Group^1 and r/ScienceAMAs^1$

[1]Affiliation not available

April 17, 2023

Abstract

Hello Reddit! We are excited to be here to share our expertise in the field of fabrication and testing of mirrors and other optical surfaces. Joining me (Dae Wook) in answering questions are my students Logan Graves and Isaac Trumper, who specialize in developing these types of measurement tools. We specialize in making very large telescopes of world renowned quality. We can do this only through understanding exactly how to make, and then test, the mirrored surfaces. You may have heard of one of our current projects, the Giant Magellan Telescope (GMT), but we like to call it a giant camera! This telescope is designed to investigate events just after the Big Bang, such as how galaxies formed. It will do an amazing job at collecting light in order to view very faint objects in the sky. We also work on other exciting projects such as a giant microscope (DKIST), and a giant action-cam (LSST). Please take a look at our group's website to get an idea of the other types of projects we work on: http://www.loft.optics.arizona.edu/projects/. To enable these amazing telescopes, we develop fabrication and testing methods such as using silly putty to polish, or a TV and camera to display fun patterns to measure nanometer sized surface defects. We even use really hot wires to generate infrared radiation, which enables a whole different type of surface testing. Want to learn how you can make your own mirrors? Interested in amateur astronomy? Want to understand how optics and light works more? Well then come on and ask us anything! We will be back at 6 pm ET to answer your questions, ask us anything! Edit: Hello Reddit, we are live! Edit: Hello Reddit, we are leaving for now and will come back later for some follow-ups if there are any more questions/comments. We enjoyed it! Thank you.

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READ REVIEWS

WRITE A REVIEW

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Lens and mirrors have dominated astronomy for hundreds of years, but new nanophotonic detectors such as optical-phased arrays are showing promise, and pulling in some major funding. Do you feel these new technologies will be as impactful on astronomy as adaptive optics? As the size of new telescope grows ever larger, the construction time and cost also increase. Do you feel there could be a day when a observatory under construction could be leap-frogged by new technology? Is the construction of these facilities flexible enough to adopt new technology during the building phase?

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Thank you for the interesting question, which let us also think about the possibilities using such a new technology. I believe this is why this kind of public AMA really opens up new ideas and concepts! In astronomical optics, the main driving factor was creating a "large" optical surface in order to collect as many photons as possible since human's goal is to time travel back to the beginning of the universe

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(e.g. soon after the Big Bang event) by looking at far away objects more than 13 billion light years from Earth. Yes, they are very "faint" and you need very large optics to focus them in to a detector.

This was exactly the reason for the dramatic transition from the lens-age to the mirror-age. While mirrors could be supported from behind in order to maintain their surface shapes (due to the gravitational deflections and/or other effects), lens needs to be mounted along the perimeter. For instance, an 8 meters in diameter lens weighs about 200 tons, and if held from the perimeter, will be broken by its own weight. Also, a mirror is achromatic (e.g. all wavelengths reflect in the same manner) while lens (or many other optical photonics components) are wavelength dependent. Such an achromatic system enables astronomers, physicists and scientists to study various spectrums of the objects (or dark matter, dark energy, etc…) in the universe.

What will be the next breakthrough? Definitely, such an optical-phased arrays could be a new break through as we never know the potentials until we know. However, there are a few key things required to be a solid candidate. As I mentioned briefly, astronomers often want achromatic systems. For instance, the deformable mirror which is often used in modern adaptive optics systems, is an achromatic component. (v.s. Photonics-based components are usually wavelength dependent.) Also, the wavefront correct-ability without adding noise becomes critical. While the speed of a photonics-based component could be sufficient (e.g. >1-2 kHz) to compensate the atmosphere for an adaptive optics system, the dynamic range of a wavefront manipulation, precision of the control, and its noise characteristic needs to meet the requirements.

An observatory is a continuously evolving scientific instrument (or a Pokemon?). In contrast to a space telescope, which is very difficult to upgrade or change the instruments once it is launched, the ground-based telescopes/observatories can be and have been continuously adapting newly available sensors, detectors, optical systems, spectrometers, laser guide star systems, etc…

These "extremely" large telescopes are something we, human, never built one before. It is taking 10-30 years to build one from the concept. So, there have been many real-time challenges and new technologies have been proposed, investigated and applied. For instance, a silly-putty tool was developed and used to polish the world's most aspheric mirror, the 8.4 m first off-axis segment of Giant Magellan Telescope. A hot-wired based infrared TV was made in-house and used to measure the 4.2 m primary mirror of the Daniel K. Inouye Solar Telescope.

You'll probably consider this a very basic question but I am aware that mirrors are also used in laser devices so I was wondering, how do the surface materials of mirrors in laser devices differ from the surface materials of mirrors used in telescopes?

Nothinbutrunnin

It is not a basic question at all. As matter of fact, such a laser application mirror manufacturing/coating is a very active and challenging research area today.

Although details will depend on specific cases, in general, mirrors in laser systems requires superior surface quality and special coatings (e.g. Anti-reflection coatings on lens surfaces) since any ghost reflection or stray-light (i.e. unwanted) can degrade the lasing performance. Also, any internal stresses, sub-surface damage, or small scale surface imperfections could cause a permanent damage on the optics and the "expensive" optics need to be replaced. Especially, short-wavelength lasers have much tighter and challenging specifications since the surface quality needs to be good compared to its wavelength. For instance, if your laser system is working at 50 nanometer wavelength, your surface roughness often needs to be well under a few angstrom RMS. One of the most powerful and exciting laser systems in the world could be the National Ignition Facility (NIF) at the LLNL. Check out their amazing science. Also, for high power laser applications, the coating needs to be strong enough to withstand the laser energy arriving on to the lens surfaces.

In contrast, the "extremely" large astronomical mirrors require large areas in order to harvest as many photons as possible from more than 10 billion light years away from the telescope. Shaping such a large optical surface down to better than 10-20 nanometers RMS form accuracy is one of the most challenging part of the mission. An outstanding surface micro roughness for an 8.4m in diameter mirror surface could be less than 2 nanometer RMS as many astronomical sciences (using ground-based extremely large telescopes) focus on visible and infrared wavelengths. Once the mirror surface is shaped and polished (after usually 2 years of fabrication for a mirror), the mirror is coated with high reflectance coatings (e.g. Aluminum). It is not really about the coating needing to be robust against high energy from the source since stars and galaxies are very faint (unfortunately). It is more about having a method to re-coat such a giant optics up at the high mountain tops once the mirror surface collects enough dusts, unwanted debris from wild animals (e.g. birds) every 1-2 years. Large observatories usually have large vacuum chambers so that the re-coating can be done on site. At last, a novel coating approach was implemented at the Large Binocular Telescope, which bring a chamber lid to the telescope instead of transferring the giant mirrors to the neighboring coating facility.

I wish you liked the answer. We, Dae Wook, Logan and Isaac also had a good time to come up with this answer! Thanks!