Next-generation optics offer the widest real-time views of vast regions of the sun

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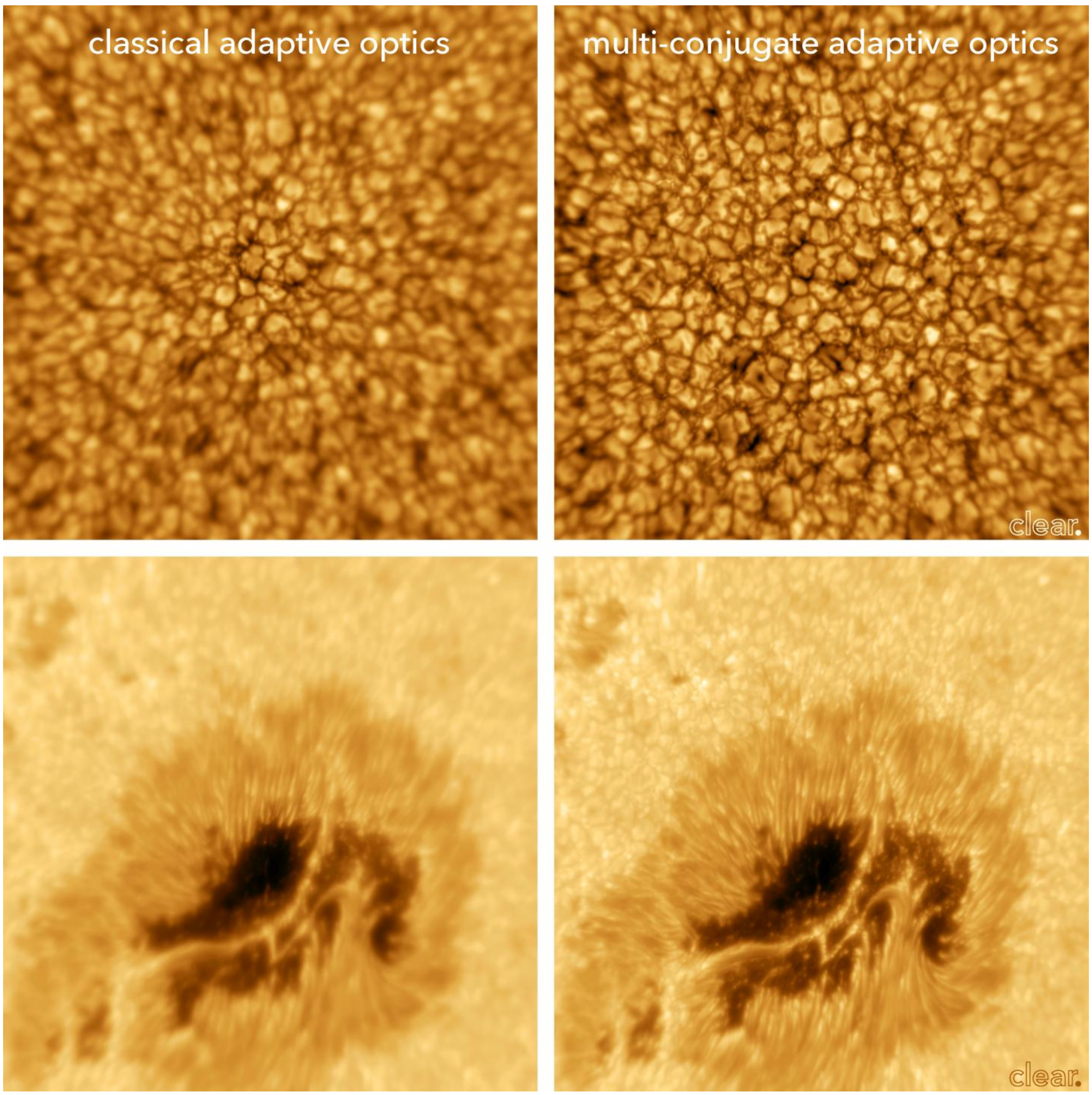

Recent images taken from Big Bear Solar Observatory of a massive section of the Sun's surface, about 23,000 miles square, showcase the advances in real-time clarity over vast distances presented by a groundbreaking new optics system. Credit: Big Bear Solar Observatory

A groundbreaking new optical device, developed at NJIT's Big Bear Solar Observatory (BBSO) to correct images of the Sun distorted by multiple layers of atmospheric turbulence, is providing scientists with the most precisely detailed, real-time pictures to date of solar activity occurring across vast stretches of the star's surface.

The observatory's 1.6-meter New Solar Telescope can now produce simultaneous images, for example, of massive explosions such as solar flares and coronal mass ejections that are occurring at approximately the same time across large structures such as a 20,000-mile-wide sunspot in the Sun's photosphere.

"To understand the fundamental dynamics of the Sun, such as the origin of solar storms, we need to collect data from as wide a field of view as possible," says Philip Goode, distinguished research professor of physics at NJIT and the leader of an international team of researchers funded by the National Science Foundation (NSF) to develop this next-generation optical system.

"During large flares, for example, magnetic field changes appear to occur at many different places with near simultaneity," he explains. "Only by seeing the comprehensive array of eruptions all at once will we be able to accurately measure the size, strength and sequencing of these magnetic events and also analyze the forces that propel the star's magnetic fields to twist around each other until they explode, spewing massive amounts of radiation and particles that, when directed earthward, can cause disruptive space weather."

The multi-conjugate adaptive optics (MCAO) device sits downstream of the aperture of the BBSO telescope, currently the world's highest-resolution solar telescope. The system is composed of three mirrors that change shape to correct the path of the incoming light waves, guided by a computer attached to ultra-fast cameras that take more than 2,000 frames per second to measure aberrations in the wave path. The system is called multi-conjugate because each of the three mirrors captures light from a different altitude - near the ground and at about three and six miles high - and the three corrected images together produce a distortion-free picture that eliminates the effects of turbulence up to about seven miles.

The MCAO system has tripled the size of the corrected field of view now available with the current technology, known as adaptive optics, which employs a single shape-shifting, or deformable, mirror to correct images. An article showcasing these advances was published today in the journal *Astronomy & Astrophysics*.

"The gain of using three deformable mirrors instead of one is easily visible. The images are crisp in a much larger area," says Dirk Schmidt, a post-doctoral researcher at the National Solar Observatory (NSO), a project scientist for the international MCAO team, and first author of the article describing the research. "After many years of development, this is an important milestone for the new, wide-field generation of solar adaptive optics."

Turbulent airflows at different layers of the Earth's atmosphere, from the ground up to the jet stream, change the path of the Sun's light faster than the human eye can compensate, blurring the images captured by conventional telescopes just as hot exhaust creates a haze on the roadway. The blurring occurs when air masses at different temperatures mix, distorting the propagation of the light and causing it to take an ever-changing, random path from the distant object, arriving at the observer with a randomized angle of incidence. That same atmospheric turbulence causes the twinkling of stars.

The MCAO team, which includes researchers from NJIT, NSO and the Kiepenheuer Institute for Solar Physics in Germany, has been working together for more than a decade on the next generation of adaptive optics to correct these distortions. The researchers succeeded in significantly widening the field of view after several years of alternating laboratory experimentation - with an artificial light source functioning as the Sun that emitted light waves purposefully distorted by the heat emanating from hot plates - with "on-sky" tests performed in real time in the BBSO's optical path.

"Over the years, we had reconfigured the mirrors scores of times, waiting for that 'Wow!' moment," Goode recalls. "Finally, late last July, we saw what we had long sought - a continuous stream of sharp, wide-field corrected, but essentially identical images. There was stunned silence, followed by applause. We then repeated the test several times by looking at various places on the Sun to prove we had succeeded. The final trick was narrowing the field to get a deeper-focused correction with each mirror, much like you would adjust a camera to have the near and far field in focus."

The scientific gains are expected to be multi-level. A clearer, more comprehensive view of solar activity should provide additional clues to researchers seeking to explain mysterious dynamics, such as the means by which explosions on the Sun produce magnetic explosions and radiation and accelerate particles to nearly the speed of light within seconds. The more scientists understand physical processes taking place more than 90 million miles away, the better policymakers will be able to predict and prepare for solar storms with the ferocity to disrupt communications satellites, knock out GPS systems, shut down air travel and quench lights, computers and telephones in millions of homes and businesses, notes Andrew Gerrard, director of NJIT's Center for Solar-Terrestrial Research, which operates the BBSO and several other solar instruments around the world and in space.

"Correcting for multiple layers of turbulence in the atmosphere is an engineering tour-de-force," comments Peter Kurczynski, director of the astronomical sciences program at the NSF that funded the research. "This study demonstrates technology that is crucial for next-generation observatories and it will improve our understanding of the sun. This is why NSF supports adaptive optics research, because new technologies enable scientific discoveries."

The MCAO project also serves as a critical test of optical instruments that will be required by future solar telescopes.

"The MCAO results from BBSO constitute a real break though," notes Thomas Rimmele, who is the project director for the coming 4-meter Daniel K. Inouye Solar Telescope (DKIST) in Hawaii, an associate director of the NSO and a co-investigator on the MCAO team. He adds, "The system provides an essential experimental platform for the development of wide-field adaptive optics for solar observations, and serves as the pathfinder for adaptive optics systems on the DKIST, scheduled for regular operation in 2020."

More information: Dirk Schmidt et al, widens the field for observations of the Sunwith multi-conjugate adaptive optics, *Astronomy & Astrophysics* (2017). DOI: 10.1051/0004-6361/201629970

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