Doubling the number of known gravitational lenses

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Examples of gravitational lenses found in the DESI Legacy Survey data. Credit: KPNO/CTIO/NOIRLab/NSF/AURA/Legacy Imaging Survey

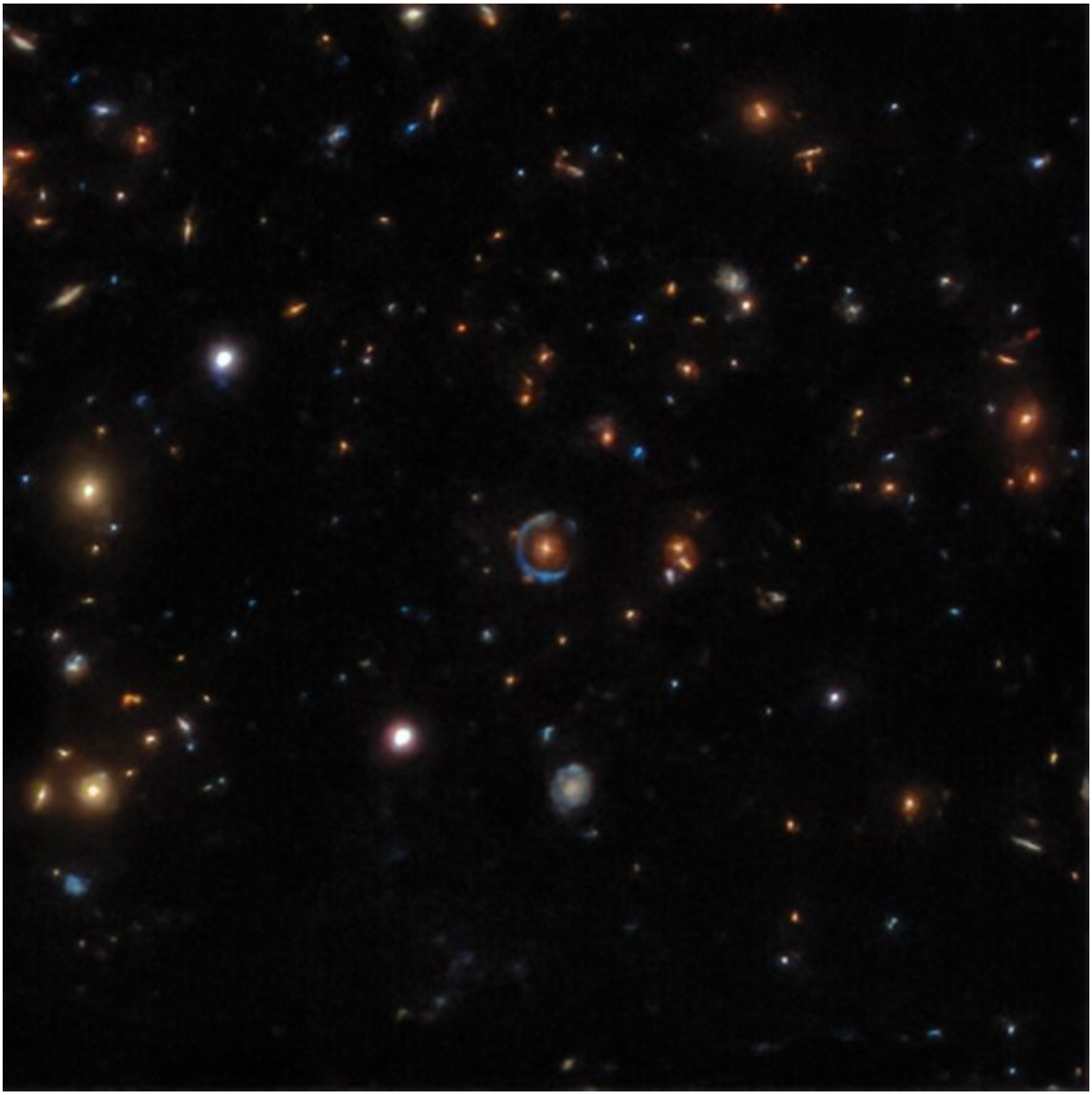
Data from the DESI (Dark Energy Spectroscopic Instrument) Legacy Imaging Surveys have revealed over 1200 new gravitational lenses, approximately doubling the number of known lenses. Discovered using machine learning trained on real data, these warped and stretched images of distant galaxies provide astronomers with a flood of new targets with which to measure fundamental properties of the Universe such as the Hubble constant, which describes the expanding Universe.

Astronomers hunting for gravitational lenses utilized machine learning to inspect the vast dataset known as the DESI Legacy Imaging Surveys, uncovering 1210 new lenses. The data were collected at Cerro Tololo Inter-American Observatory (CTIO) and Kitt Peak National Observatory (KPNO), both Programs of the National Science Foundation's NOIRLab. The ambitious DESI Legacy Imaging Surveys just had its ninth and final data release.

Discussed in scientific journals since the 1930s, gravitational lenses are products of Einstein's General Theory of Relativity. The theory says that a massive object, such as a cluster of galaxies, can warp spacetime. Some scientists, including Einstein, predicted that this warping of spacetime might be observable, as a stretching and distortion of the light from a background galaxy by a foreground cluster of galaxies. The lenses typically appear in images as arcs and streaks around foreground galaxies and galaxy clusters.

Only one in 10,000 massive galaxies are expected to show evidence of strong gravitational lensing, and locating them is not easy. Gravitational lenses allow astronomers to explore the most profound questions of our

Universe, including the nature of dark matter and the value of the Hubble constant, which defines the expansion of the Universe. A major limitation of the use of gravitational lenses until now has been the small number of them known.



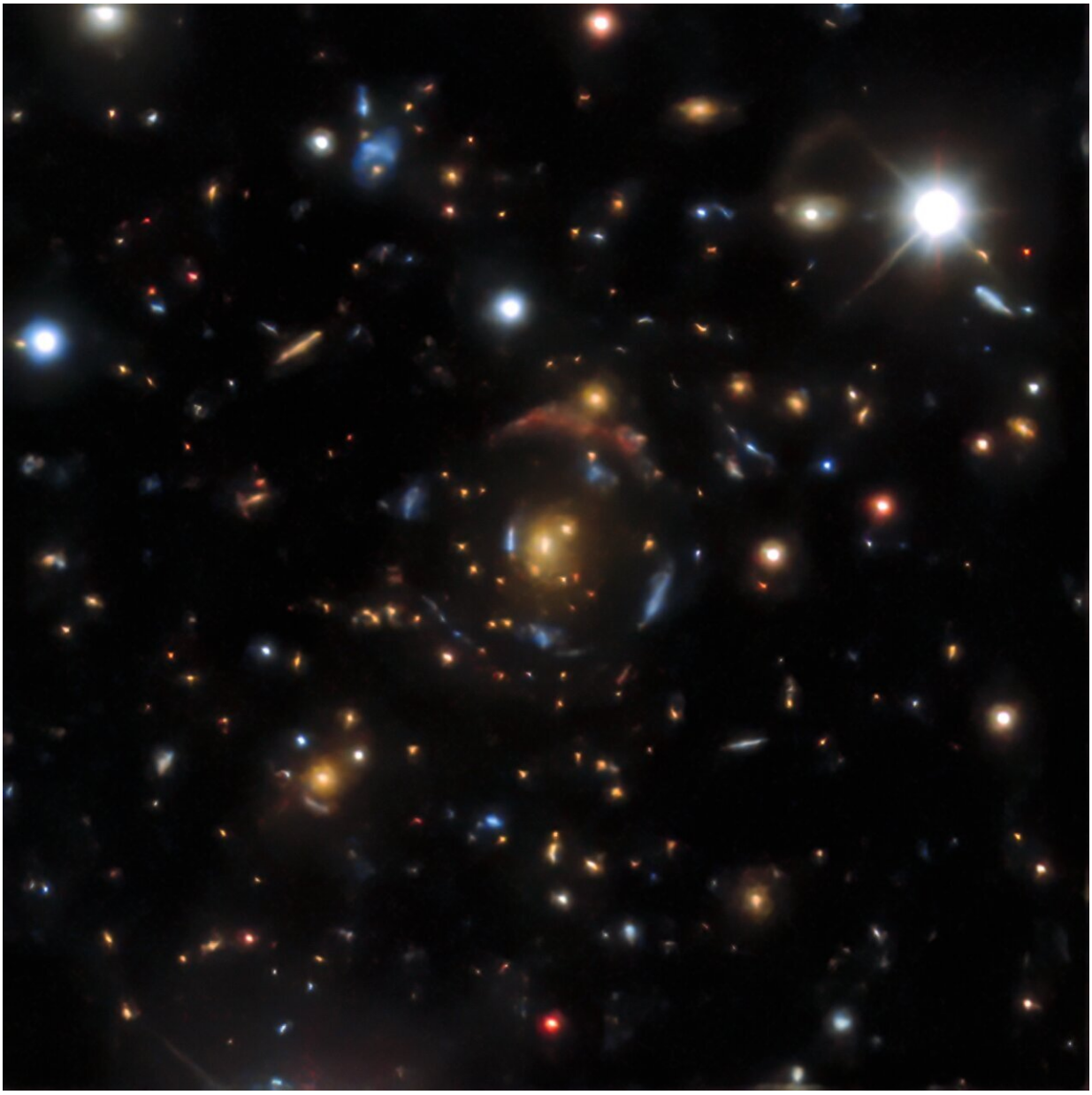
An example of a gravitational lens found in the DESI Legacy Surveys data. The nearly complete circle in the middle of DESI-015.6763-14.0150 is the image of

a background galaxy, gravitationally warped (lensed) by the red galaxy at the center into a near-perfect Einstein ring. Credit: KPNO/CTIO/NOIRLab/NSF/AURA/Legacy Imaging Survey

"A massive galaxy warps the spacetime around it, but usually you don't notice this effect. Only when a galaxy is hidden directly behind a giant galaxy is a lens possible to see," notes the lead author of the study, Xiaosheng Huang from the University of San Francisco. "When we started this project in 2018, there were only about 300 confirmed strong lenses."

"As a co-leader in the DESI Legacy Surveys I realized this would be the perfect dataset to search for gravitational lenses," explains study co-author David Schlegel of Lawrence Berkeley National Laboratory (LBNL). "My colleague Huang had just finished teaching an undergraduate class on machine learning at the University of San Francisco, and together we realized this was a perfect opportunity to apply those techniques to a search for gravitational lenses."

The lensing study was possible because of the availability of science-ready data from the DESI Legacy Imaging Surveys, which were conducted to identify targets for DESI's operations, and from which the ninth and final dataset has just been released. These surveys comprise a unique blend of three projects that have observed a third of the night sky: the Dark Energy Camera Legacy Survey (DECaLS), observed by the Dark Energy Camera (DECam) on the Víctor M. Blanco 4-meter Telescope at CTIO in Chile; the Mayall z-band Legacy Survey (MzLS), by the Mosaic3 camera on the Nicholas U. Mayall 4-meter Telescope at KPNO; and the Beijing-Arizona Sky Survey (BASS) by the 90Prime camera on the Bok 2.3-meter Telescope, which is owned and operated by the University of Arizona and located at KPNO.



An example of a gravitational lens found in the DESI Legacy Surveys data. There are four sets of lensed images in DESI-090.9854-35.9683, corresponding to four distinct background galaxies — from the outermost giant red arc to the innermost bright blue arc, arranged in four concentric circles. All of them are gravitationally warped — or lensed — by the orange galaxy at the very center. Credit: NOIRLab

"We designed the Legacy Surveys imaging project from the ground up as a public enterprise, so that it could be used by any scientist," said study co-author Arjun Dey, from NSF's NOIRLab. "Our survey has already yielded more than a thousand new gravitational lenses, and there are undoubtedly many more awaiting discovery.

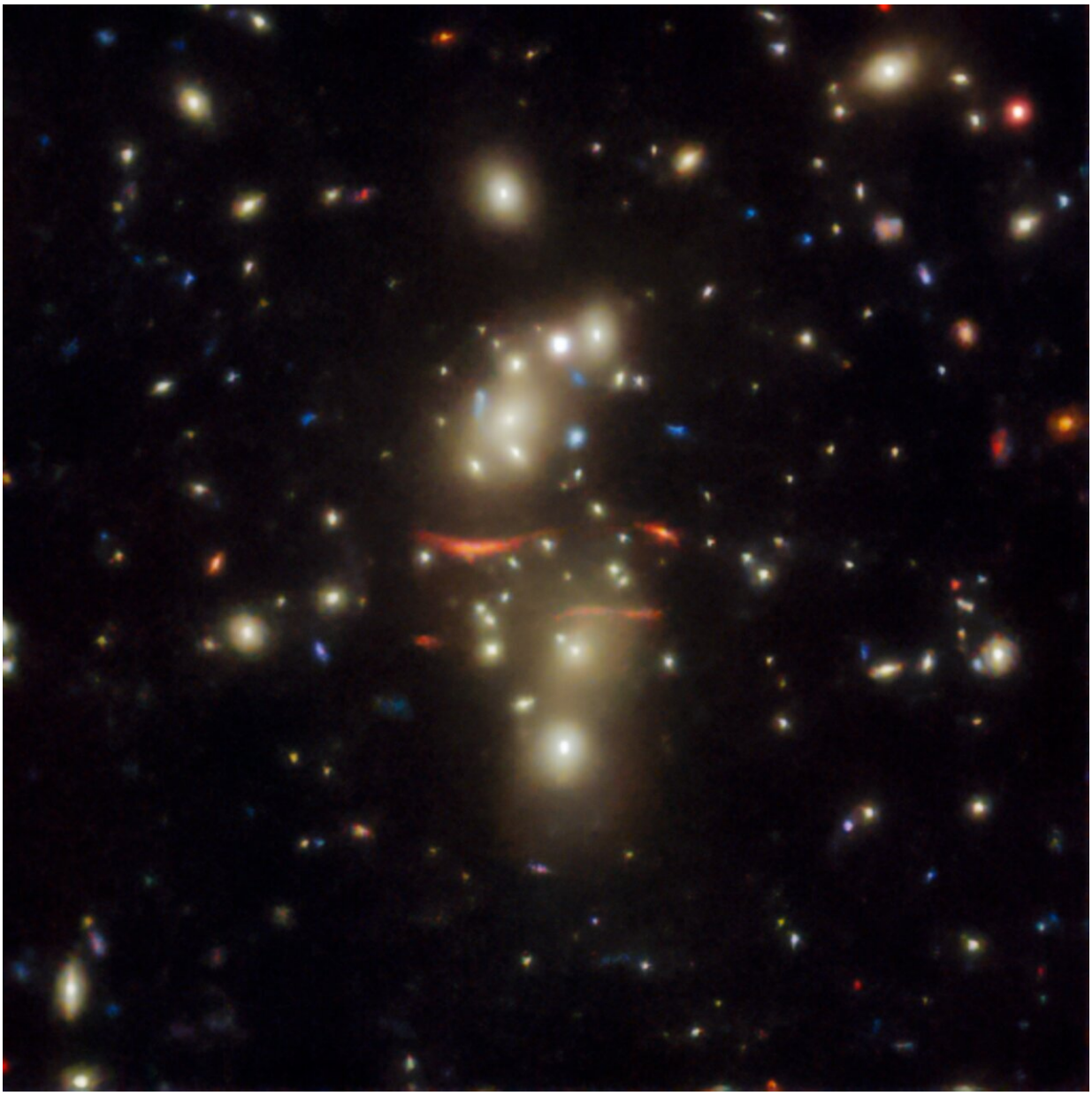
The DESI Legacy Imaging Surveys data are served to the astronomical community via the Astro Data Lab at NOIRLab's Community Science and Data Center (CSDC). "Providing science-ready datasets for discovery and exploration is core to our mission," said CSDC Director Adam Bolton. "The DESI Legacy Imaging Surveys is a key resource that can be used for years to come by the astronomy community for investigations like these."

To analyze the data, Huang and team used the National Energy Research Scientific Computer Center's (NERSC) supercomputer at Berkeley Lab. "The DESI Legacy Imaging Surveys were absolutely crucial to this study; not just the telescopes, instruments, and facilities but also data reduction and source extraction," explains Huang. "The combination of the breadth and depth of the observations is unparalleled."

With the huge amount of science-ready data to work through, the researchers turned to a kind of machine learning known as a deep residual neural net. Neural nets are computing algorithms that are somewhat comparable to a human brain and are used for solving artificial intelligence problems. Deep neural nets have many layers that collectively can decide whether a candidate object belongs to a particular group. In order to be able to do this, however, the neural nets have to be trained to recognize the objects in question.

With the large number of lens candidates now on hand, researchers can make new measurements of cosmological parameters such as the Hubble constant. The key will be to detect a supernova in the background galaxy,

which, when lensed by a foreground galaxy, will appear as multiple points of light. Now that astronomers know which galaxies show evidence for strong lensing, they know where to search. New facilities such as the Vera C. Rubin Observatory (currently under construction in Chile and operated by NOIRLab) will monitor objects like these as part of its mission, allowing any supernova to be measured rapidly by other telescopes.



An example of a gravitational lens found in the DESI Legacy Surveys data. The two red streaks near the middle of DESI-010.8534-20.6214 are the gravitationally lensed arcs (“straight” arcs) — highly magnified and stretched images — of background galaxies. The gravitational lens responsible for this warping is, collectively, the two concentrations of orange galaxies above and below the straight arcs. Credit: KPNO/CTIO/NOIRLab/NSF/AURA/Legacy Imaging Survey

Undergraduate students played a significant role in the project from its beginning. University of California student Andi Gu said, "My role on the project has helped me develop several skills which I believe to be key for my future academic career."

This research was presented in the paper "Discovering New Strong Gravitational Lenses in the DESI Legacy Imaging Surveys" to appear in The *Astrophysical Journal*.

More information: X. Huang, et al. Discovering New Strong Gravitational Lenses in the DESI Legacy Imaging Surveys. arxiv.org/abs/2005.04730 arXiv:2005.04730v3 [astro-ph.IM]

Provided by NSF NOIRLab

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