An image of a lensed quasar taken by the Hubble Space Telescope. The gravitational field of a foreground galaxy acts like a lens on the incoming quasar light rays and creates four almost evenly distributed quasar images around the lens galaxy.

Picture credit: ESA/Hubble, NASA, Suyu et al.

Link

wwwmpa.mpa-garching.mpg.de/~suyu

Lenses Made from Pure Gravity Help **to Solve a Cosmic Contradiction**

Galaxies are so massive that they bend the space around them, thus creating lenses that refract light. This phenomenon is allowing physicist Sherry Suyu to measure exactly how fast the universe is expanding with the help of images from the Hubble Space Telescope. Her method could solve a heated scientific dispute.

Kurzfassung · Langfassung: www.tum.de/faszination-forschung-26

Linsen aus purer Schwerkraft zur Auflösung eines kosmischen Widerspruchs

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Die Geschwindigkeit, mit der sich das Universum ausdehnt, angegeben durch die Hubble-Konstante, ist eine der aktuell umstrittensten Fragen der Astrophysik. Einer Kollaboration namens H0LiCOW um die Physikerin Prof. Sherry Suyu gelang es nun, die Hubble-Konstante mit einer völlig neuen Methode zu messen. Dazu untersuchte man Quasare – besonders lichtstarke kosmische Objekte –, die sich hinter Galaxien befinden. Durch die Masse der Galaxien entstehen sogenannte Gravitationslinsen, die das Bild des jeweiligen Quasars in mehrere Bilder aufspalten, deren Licht unterschiedlich lang durch den Raum unterwegs ist. Der Unterschied beträgt bei einer Laufzeit von mehreren Milliarden Jahren mehrere Tage bis Wochen. Mithilfe des Hubble-Weltraumteleskops konnte dieses Phänomen nun so genau vermessen werden, dass Suyu und ihr Team daraus die Hubble-Konstante bestimmen konnten, was ein neues Licht auf bisher widersprüchliche Messungen der Konstante wirft. Für diese Arbeit erhält Suyu den Berkeley-Preis der Amerikanischen Astronomischen Gesellschaft für das Jahr 2021. Suyu ist Professorin für Beobachtende Kosmologie an der TUM und leitet eine Forschungsgruppe am Max-Planck-Institut für Astrophysik. □

Hubble Space Telescope observations of lensed quasars. Large galaxies in the foreground act as gravitational lenses and create multiple images. For each image, the light rays travel slightly different distances and thus take a different amount of time to reach Earth. The Hubble constant can be determined from these time delays. ▷

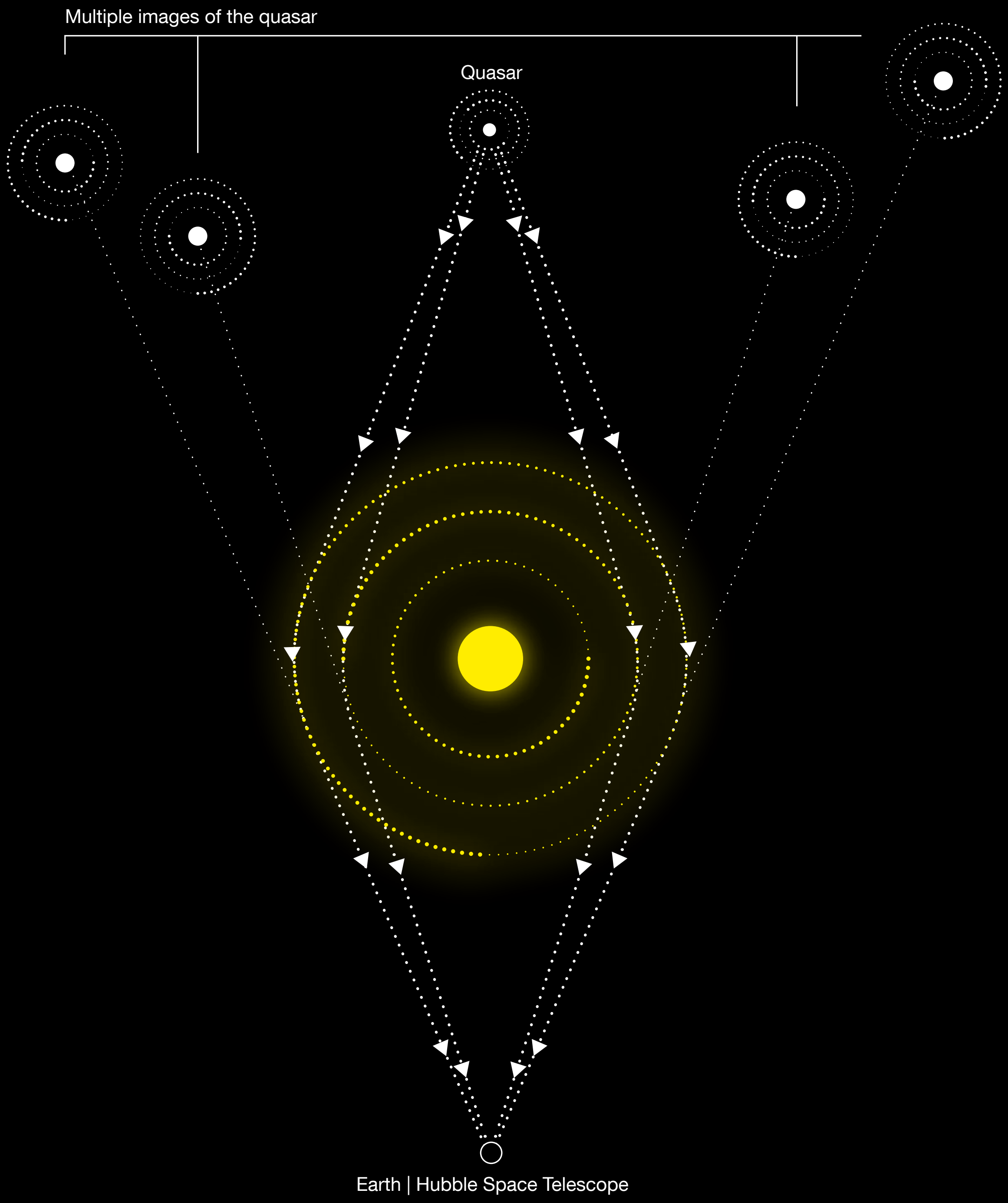
"For decades, people could only speculate about the value of the Hubble constant."

Sherry Suyu

When Professor Sherry Suyu calls her team into an online meeting, they do not just exchange updates – they also wind up laughing a lot. "We have our fun," admits the researcher, whose project revels in the name H0LiCOW. Behind this whimsical series of letters and numbers lies not only a fairly technical project name but also one of the most spectacular findings in astrophysics research of the past few years. If this was not widely known before Suyu – who leads the project – was named as a recipient of the American Astronomical Society's Berkeley Prize, which she will soon be collecting, then it will be now. Suyu is Professor of Observational Cosmology at TUM and leads a research group at the Max Planck Institute for Astrophysics.

The fact that the researcher's team is meeting online is not just down to the coronavirus pandemic. Apart from Suyu's Munich-based colleagues, the group is spread so far across the globe that the team has only one face-to-face meeting a year – which this year had to be canceled for the first time ever. However, this bitter pill has been sweetened somewhat by the success of their work. The people in Suyu's team do not shy away from vast distances – after all, this is what their research is all about.

Specifically, they are studying how our universe has become what it is today, and how it will develop in the future. One key measurement in this research field is the Hubble constant, which states how quickly the universe is expanding. Its precise value has far-reaching consequences that stretch beyond the boundaries of astrophysics and deep into the foundations of physics itself, because processes on an astronomical scale cannot yet be explained satisfactorily using current physical theories. Over the past few years in particular, it has become increasingly clear that there appears to be a startling gap in our understanding of how the universe is expanding. ▷



Graphics: ediundsepp (source: Suyu et al.)


Hubble observations of different quasars and foreground galaxies. The gravitational fields of the galaxies act as gravitational lenses and create multiple images (bright dots) of the quasars. These and other quasars were studied by the H0LiCOW collaboration to make an independent measurement of the Hubble constant.

How quickly is the universe expanding?
"For decades, people could only speculate about the value of the Hubble constant," Sherry Suyu explains. "In the 80s and 90s, some thought it was around 50, others about 100." Bringing an end to this debate was one of the motivations for constructing the Hubble Space Telescope, the first optical telescope capable of capturing images of galaxies and stars directly in space, without any atmospheric distortion. It enabled precise measurements of distances to faraway objects, something that was intended to help calculate the Hubble constant accurately for the first time. "The result was published in 2001," Suyu says. "Prof. Wendy Freedman and her team determined the Hubble constant to be 72, so roughly in the middle." This put the debate to bed for the time being, she explains. Around ten years later, however, it flared up again. Observations of the cosmic background radiation – a kind of echo from the Big Bang – opened the door to a new way of measuring the Hubble constant, although these measurements indicated a lower value of about 67. At the same time, however, work being done by Nobel laureate Prof. Adam Riess and his team also enabled distances to be measured even more accurately, making it increasingly unlikely that a simple solution to the conundrum would be found. "There was a discrepancy between the two results, and nobody knew where it came from," Suyu explains. The debate was fierce, she reveals, especially since the views of the rival camps had become entrenched. So groups of researchers all over the world set to devising new, independent ways to calculate the Hubble constant – and Sherry Suyu was one of them. She saw how she could use methods from her field of research to potentially resolve the dispute.

Picture credit: ESA/Hubble, NASA, Suyu et al.

Lenses in outer space

Suyu was looking into gravitational lensing, an effect that can be observed around large concentrations of mass in the universe such as galaxies and galaxy clusters. These act like lenses and literally distort the images of objects that lie behind them.

The fact that mass bends space and thus even refracts light has been known for a long time. The effect is not always as strong as around black holes, which literally swallow light. Large but less dense clusters of mass make objects behind them appear distorted or even duplicated in the sky, like mirror images. Gravitational lenses of such strength were first observed in 1979. The light from the various images of the same object can take different spans of time to travel through space and reach us, like waves in the sea that go around an island and cause a boat to rock at a certain point behind it. Suyu was aware of a Swiss collaboration called COSMOGRAIL, which was specifically studying the images of quasars influenced by gravitational lensing. Quasars are extremely luminous objects whose brightness flickers like candlelight. As the light from the various images of a quasar travels for different amounts of time in space, the flickering pattern sometimes appears after a delay of days or weeks – similar to an echo that you hear late as the sound has to travel a certain distance and back. “To be able to measure that with the necessary degree of accuracy, you need several years’ worth of observational data,” Suyu says. “Fortunately, Prof. Frédéric Courbin, Prof. Georges Meylan, and their research group began their observational program – called COSMOGRAIL – back in 2004.” Suyu knew that this effect could be used to measure the Hubble constant, because the universe has been expanding significantly during the light’s several-billion-year journey through space. This expansion exerts a measurable influence on the traveling time of the light in the individual images of the quasar. And the fact that the speed of the expansion is linked to the Hubble constant allows conclusions to be drawn about it. Suyu got in touch and launched H0LiCOW, with the “H0” being the abbreviation for the Hubble constant, the “L” signifying “lens” and the “COW” element standing for “COSMOGRAIL’s Wellspring”.

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Prof. Sherry Suyu

Astrophysicist Sherry Suyu is Professor of Observational Cosmology at TUM, where she is employed via the Max Planck@TUM program. Originally from Taiwan, she studied astrophysics in Canada and California and spent time researching in Bonn, Santa Barbara, Stanford, and Taipei before joining TUM in 2016. She leads a research group at the Max Planck Institute for Astrophysics. Prof. Suyu has received numerous awards and will be presented with the American Astronomical Society's Lancelot M. Berkeley Prize for her H0LiCOW project in 2021. In her free time, she enjoys playing badminton competitively and traveling.

"Although both teams, mine and COSMOGRAIL's, had the same objective, we each lacked what the other had," the physicist reveals. Even as a young researcher while studying in California, she used telescope images to measure mass distribution in galaxies. Since then, she has refined her methods further together with her Munich-based colleagues Dr. Stefan Taubenberger and Dr. Akın Yıldırım. This was key, since knowing the exact distribution of mass is crucial to calculating the strength of the lens and thus the time lag in the images. Once all these pieces of the puzzle are in place, the Hubble constant can be calculated.

Observations through the Hubble Space Telescope

That is the theory, anyway. Only one telescope would be good enough, however, to get the ultra-precise images of the lens galaxies that were needed. Sherry Suyu applied to use the Hubble Space Telescope. "It's very hard to get observation time on it," she says. But her application was accepted. Suyu got hold of the Hubble manual and began planning her next steps. "When the first pictures from Hubble arrived, it was all very exciting," she recounts. The actual analysis of the images was an extremely laborious process. "This was partly because we were conducting a blind analysis," the researcher explains. "We'd processed the data in such a way that we wouldn't know what result we were going to get until the very end." They did this to avoid any preconceptions that could potentially bias their result in this sensitive and heated debate. "We agreed to publish our findings either way, regardless of what the outcome was." Revealing the final result was thus a special moment which required all group members to concur that the analysis was complete. This was arranged at a group meeting in Copenhagen, where the whole international team met to share their thoughts. They were struck by their result: the value they had determined for the Hubble constant was a perfect match for the figure calculated by measuring the distance to faraway objects and differed from that derived from background radiation.

But the debate had not been settled for good, Suyu says: attempts continued at uncovering mistakes and inaccuracies in measurement that could explain the discrepancy in the two measurements of the Hubble constant. But the idea that new physical effects, rather than errors, are to blame now seems more plausible than ever. For instance, a new form of dark energy – that mysterious effect that is further accelerating the expansion of the universe – could have existed in the early days of the universe. That would explain the differences in the measurements and thus pave the way for research into completely new physics.

Holy smokes!

In other words, the project was a major success. Now in September, in her latest online meetings with her collaborators, Suyu has already been working on getting the next project under way. Although this also involves gravitational lensing, this time she is studying supernova explosions, rather than quasars. The name of the project? HOLISMOKES – an acronym that, besides the terms "lensing", "supernovae", and "investigations", also includes words such as "highly optimised". Once again, both spectacular astrophysics and a dash of humor go hand in hand.

■ *Reinhard Kleindl*

Picture credit: Astrid Eckert/TUM