THE UNIVERSE IN A NEW LIGHT

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Six months after its launch, the James Webb telescope has delivered its first images, revealing fascinating insights into distant galaxies as well as turbulent scenarios encompassing the birth and death of stars. The space observatory has also captured the spectra of exoplanets. The Max Planck Institute for Astronomy in Heidelberg was involved in building the instruments.

"It all looks fantastic and has exceeded our already high expectations," says Oliver Krause. The scientist and his team at the Max Planck Institute in Heidelberg had been eagerly awaiting the publication of images and data on July 12. The astronomers had a long wait for this moment – originally, the telescope was supposed to lift off into space in 2007, and in the years that followed, there were repeated delays.

When the roughly ten-billion-dollar observatory finally began its journey on December 25, 2021, aboard a European Ariane 5 launch vehicle, a great deal could have gone wrong in the six months leading up to the first successful observations in the summer: experts had identified no fewer than 344 crucial sources of error before the mission began. "Single point failures" is what Oliver Krause calls them. Each of these errors would have jeopardized the project, in which the American, European, and Canadian space agencies are all involved, or even caused it to fail completely.

Indeed, the journey from launch to the operational telescope was extremely complex. "James Webb" had been sent into space practically as a construction kit, so the two most important structures had to literally unfold first: these were the five-layer solar shield the size of a tennis court and the main mirror consisting of 18 honeycombs, which has a diameter of 6.5 meters.

During the unpacking, the engineers and technicians had to make sure that all the mechanical processes ran perfectly and without error. For the sunshield, for example, 107 bolts and springs were used, while the hexagonal beryllium segments of the main mirror were pushed into the correct positions by more than 100 small motors to within a fraction of a millimeter. If one part had snagged, there would have been no one to intervene directly.

Over a period of about three months in spring 2022, the 6.5-meter telescope gradually cooled down to the operating temperature of minus 230°C. Its four scientific instruments prefer an even colder temperature – up to 267°C below zero. In addition, the observatory was carefully maneuvered to its observation post, Lagrange Point 2. "This location makes it possible to position the Sun, Earth, and

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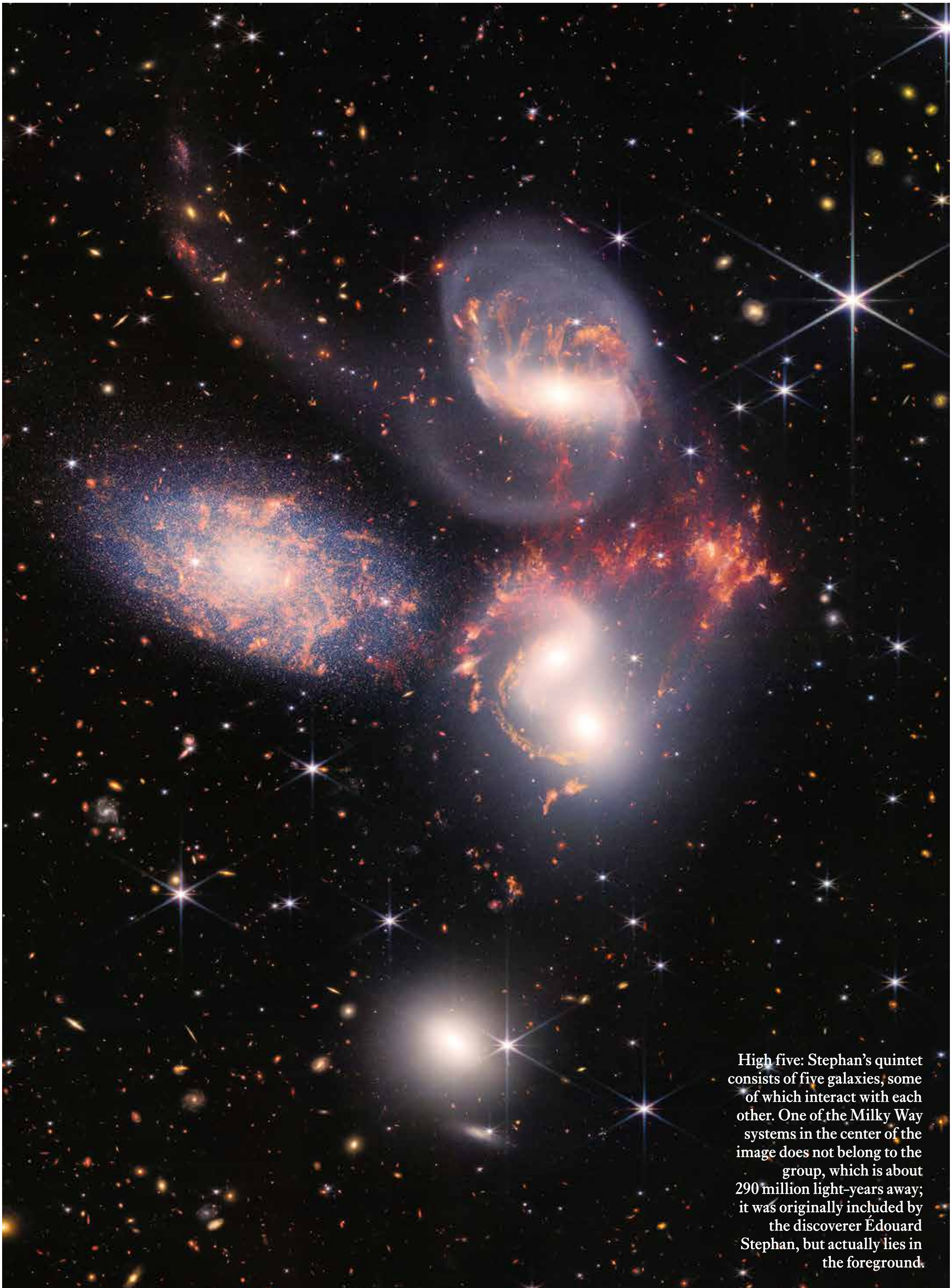

IMAGE: ESA / CSA / STSCI / NASA

High five: Stephan's quintet consists of five galaxies, some of which interact with each other. One of the Milky Way systems in the center of the image does not belong to the group, which is about 290 million light-years away; it was originally included by the discoverer Édouard Stephan, but actually lies in the foreground.

PHOTO: NASA / DESIREE STOVER

Honeycombs for the heavens: the primary mirror of the James Webb telescope consists of 18 hexagonal beryllium segments and has a diameter of six and a half meters. With it, the observatory surveys the universe in infrared light.

telescope as if strung on a string of pearls, allowing James Webb to consistently gaze into space in the shadow of the protective shield," explains Oliver Krause.

However, the space observatory is not stationary at Lagrange Point 2, located 1.5 million kilometers away from the Earth (there are a total of five such points where the gravitational forces of celestial bodies balance each other out). Rather, it orbits it on a path whose diameter is larger than the distance between the Earth and the Moon. It takes half a year to complete one circuit, whereby the telescope's control nozzles must constantly ensure precise choreography.

Before the first images and data could be obtained, the four scientific onboard instruments first had to go into operation. Krause and his group had intensively followed and supported the preparatory work during this phase. One of the instruments, for example, known as MIRI (Mid-Infrared instrument), contains a filter wheel that was developed and built at the Max Planck Institute for Astronomy. With MIRI, the telescope surveys the cosmos in mid-infrared light, while with NIRCam (Near Infrared Camera) it makes observations in the near infrared. The quartet of instruments is completed by the two spectrographs NIRSpec (Near Infrared Spectrograph) and FGS/NIRISS (Fine Guidance Sensor/Near InfraRed Imager and Slitless Spectrograph), both of which break down the light of cosmic objects into small rainbows, i.e., generate spectra. The telescope thus covers a wavelength range from 0.6 to 28 micrometers (thousandths of a millimeter).

Micrometeorites hit the mirror

The tests, data, and test images from early summer were already looking great. Even after several micrometeorites hit and slightly damaged the mirror, the telescope's vision was not diminished, according to the US space agency NASA. James Webb finally peered into the depths of the universe as planned – and delighted specialists and laymen alike.

One of the images shows the spectrum of WASP-96b. This gas planet, 1150

light-years away, is half the size of Jupiter and orbits its parent star once every three and a half Earth days. “You can really appreciate the telescope’s superior accuracy of measurement when you compare it to its predecessors, for example, Spitzer or Hubble,” says Maria Steinrück. The researcher at the Max Planck Institute for Astronomy works on the atmospheres of exoplanets – a research field to which the space telescope is expected to bring a whole new impetus. Department Director Laura Kreidberg has successfully submitted two observation proposals. And Maria Steinrück is convinced that “in the future, the James Webb telescope will make it possible to determine the composition of the atmospheres of exoplanets that were previously too small or too cool to measure.” In August, a second observation of an exoplanet was published: the observatory had measured infrared light filtering through the atmosphere of the hot gas giant WASP-39b, some 700 light-years away. This enabled Webb not only to record the first detailed spectrum of an alien planet in near-infrared light, but also to detect carbon dioxide in its atmosphere.

WASP-39b has only about a quarter of the mass of Jupiter, but a diameter 1.3 times larger, while in the exoplanet’s atmosphere the temperature is around 900°C. Unlike the cooler, more compact gas giants of Jupiter and Saturn in our solar system, WASP-39b – like WASP-96b – orbits its star in close proximity; its distance is only about 7 million kilometers, which is one-eighth the distance between the Sun and Mercury. The short distance means that this planet, which was discovered in 2011, is traveling at breakneck speed – one orbit takes just over four Earth days.

From our vantage point, we observe the orbit laterally. That means that WASP-39b periodically passes in front of the star and obscures it, which leads to minimal dimming. During such a transit, a small part of the star’s light passes through the planet’s atmosphere, which is thus illuminated. When this happened, the NIRspec instrument registered a small increase in brightness in the fanned-out light between 4.1 and 4.6 micrometers. This way, carbon dioxide was clearly detected on a planet outside our solar system for the first time.

“This finding is an important milestone for characterizing the atmospheres of exoplanets,” explains Max Planck astronomer Laura Kreidberg. “Carbon dioxide is an important indicator of the formation history of planets. It helps us measure the complete carbon and oxygen inventory of the atmosphere, which is very sensitive to conditions in the disk where the planet formed.” With the help of the CO_2 measurement, specialists can better narrow down, for example, the plan- →

SUMMARY

The first data and images provided by the James Webb telescope suggest many exciting discoveries.

The space observatory does its observing 1.5 million kilometers from Earth.

The four onboard scientific instruments sample the cosmos in the range of infrared light between 0.6 and 28 micrometers (thousandths of a millimeter).

Cradle of the stars: what looks like a rugged mountain range is actually a region in the Carina Nebula, about 7600 light-years away, where new suns are born.

IMAGE: ESA / CSA / STSCI / NASA

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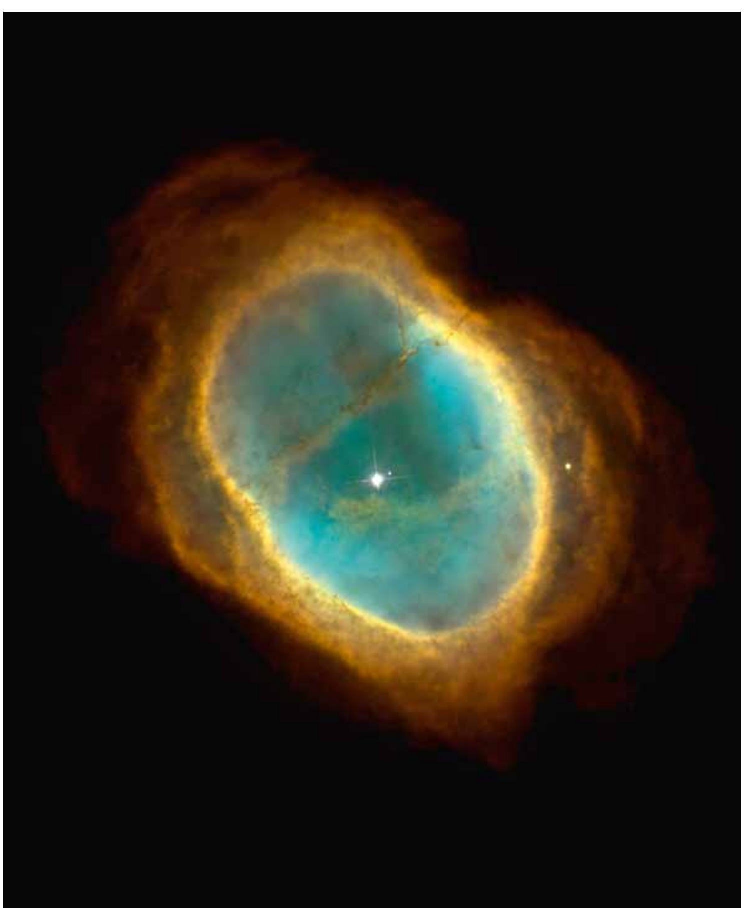

IMAGE: THE HUBBLE HERITAGE TEAM (STSCI/AURA/NASA)

et's point of origin or the properties of the solids and gases that were introduced.

Group of galaxies in Pegasus

Photos of astronomical objects are particularly attractive to the general public. Galaxies, for example, are the main motif in the image of Stephan's Quintet, an ensemble of five Milky Way systems discovered by the French astronomer Édouard Stephan in 1877 in the constellation Pegasus. The group of five, at a distance of 290 million light-years, is quite close together, with some of the members interacting with each other due to their gravitational pull. Gas swirls around, and new stars are born in droves. "The clarity and sharpness of the image is not the only thing that is special here," says Max Planck researcher Krause. In the photo, he says, the surroundings of Stephan's Quintet appear in a dramatic view. "There are many astrophysical processes reflected there that can now be studied with unprecedented precision."

Previously unknown detail and unique dynamics are also revealed in the images of the Southern Ring Nebula and the Carina Nebula. This is where the James Webb telescope shows its strength, because – unlike the famous Hubble Space Telescope – it observes not in the optical range of the electromagnetic spectrum, but in the infrared window, which is inaccessible to us humans. Webb thus sees the world with different eyes, so to speak. While the Southern Ring Nebula announces the death of a star, the Carina Nebula

A fiery finale: having reached the end of its life, a star blows its gaseous atmosphere into space, creating this Southern Ring Nebula. The added value of the James Webb telescope is evident from the object designated NGC 3132: its photo (above) is juxtaposed with an image taken by the Hubble Space Telescope (below).

resembles a cosmic delivery room in which hundreds of suns are born. Both celestial objects belong to our Milky Way and are 2000 and 7600 light-years away from Earth, respectively.

Gravitational lens reveals distant objects

In deep space, too, the observatory is opening up new dimensions. It has set its sights on the galaxy cluster SMACS J0723.3-7327, which acts like a gravitational lens. Here, the cluster of galaxies in the foreground focuses and distorts the light of the much more distant objects behind it, so that these appear – partly as multiple images and as arcs – as if seen through a magnifying glass. Before James Webb's observation, a total of 19 multiple images of six background sources were known to exist behind the cosmic gravitational lens, which is about 4.5 billion light-years from Earth. The telescope's data revealed 27 additional multiple images of ten other objects.

"The images are really amazing and so beautiful. They have enabled us to significantly refine our gravitational lensing mass model," says Gabriel Bartosch Caminha, a postdoctoral fellow at the Garching-based Max Planck Institute for Astrophysics. The researchers used their model to estimate the distance of these lensing galaxies, and the light from some objects appears to have started its journey about 13 billion years ago. Because electromagnetic radiation rushes through the cosmos at finite speed (about 300,000 kilometers per second), telescopes act like time machines: for this reason, observing celestial bodies at great distances always means looking into the past. James Webb is therefore shining a light on the early days of the universe.

Astronomers expect new findings in cosmology as well as in the study of exoplanets, the evolution of galaxies, and the development of stars. If the James Webb telescope remains in good shape and no technical defects occur, it could operate for up to two decades – enough time for a whole host of surprising discoveries.

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GLOSSARY

EXOPLANETS
are celestial bodies orbiting a distant star. To date, around 5000 such objects have been discovered. The search for exoplanets that resemble the Earth is particularly interesting.

GRAVITATIONAL LENSES
are derived from Einstein's theory of relativity. According to this theory, light from a distant source – a galaxy, for example – is influenced by the mass of an object lying in front of it from the observer's perspective, such as a galaxy cluster, as if by an optical lens. The image can be amplified, distorted, or even multiplied.

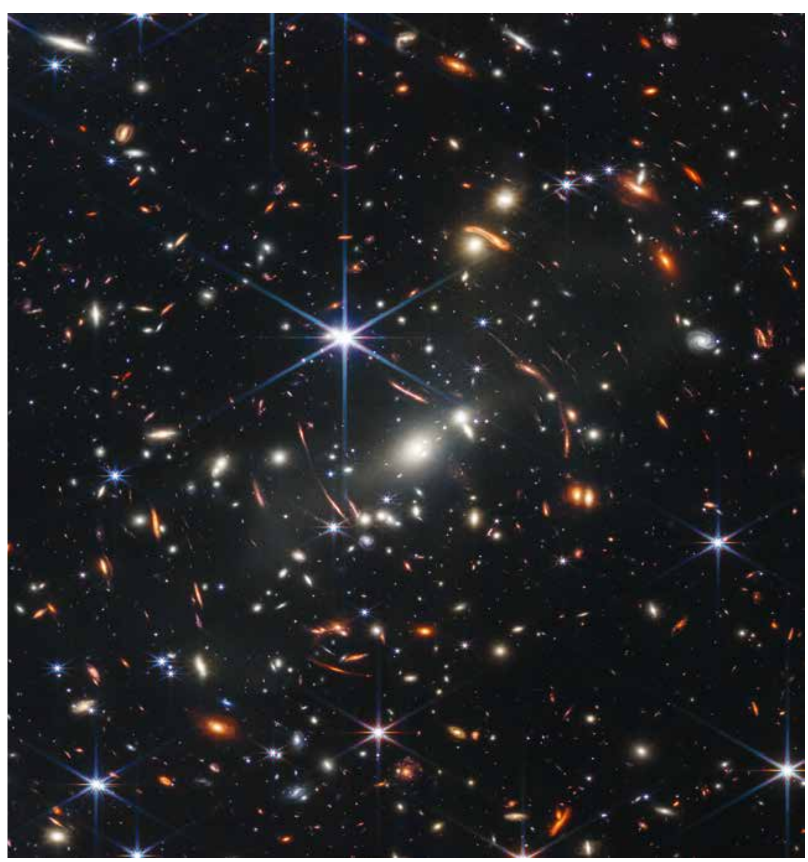

IMAGE: ESA / CSA / STSCI / NASA

A window into the past: the light emitted by some of the galaxies shown here has been traveling for more than 13 billion years. The lines and arcs are produced by the galaxy cluster SMACS J0723.3-7327, which acts as a gravitational lens.