DOI: 10.18727/0722-6691/5342

Celebrating 25 Years of Remarkable Science and Engineering with the VLT

Itziar de Gregorio-Monsalvo[1]
Michael Hilker[1]
Bruno Leibundgut[1]

[1] ESO

Twenty-five years ago, on 25 May 1998, a significant milestone was reached for ESO and for European astronomy as the Very Large Telescope (VLT) captured its first images. On the occasion of its first light, the 8-metre Unit Telescope UT1 offered impressive images of our Universe. These included a successful tracking test in the globular cluster Omega Centauri, detailed images of the central region of another globular cluster, Messier 4, the fine structure of the Butterfly Nebula, high-velocity ejecta near Eta Carinae, and a captivating picture showcasing stars, dust, and gas in Centaurus A.

Over the past 25 years the VLT has made an extensive and outstanding contribution to scientific research. More than 10 000 scientific publications have been published to date, utilising data collected from these telescopes. The VLT facility has been continuously developed, with the addition of new instruments, the combination of the unit telescopes to form a powerful interferometer, the addition of adaptive optics with lasers and the expansion of the end-to-end operations model. All VLT data are available through the ESO Science Archive Facility. Several remarkable scientific achievements have been recognised with two Nobel prizes. The VLT's exceptional instrumentation played a crucial role in establishing the accelerated expansion of the Universe and confirming the existence of a compact object at the centre of our own Galaxy. Additionally, the VLT achieved the groundbreaking feat of capturing the first direct image of an exoplanet and it has significantly contributed to our understanding of the diverse architectures of exoplanetary systems.

As part of the commemorative activities to acknowledge the construction of the VLT, on 4 December 1996 President Eduardo Frei Ruiz-Tagle of the Republic of Chile deposited a time capsule within the walls of VLT Enclosure 1 (Giacconi, 1997). This capsule, filled with nitrogen gas and hermetically sealed, contained outstanding scientific papers from every ESO member state, the host country Chile, and ESO itself, intended to be preserved for an extended period[1].

To celebrate the 25th anniversary[2] of this significant moment for ESO and the VLT the Offices for Science in Chile and Germany organised an internal event on 26 May 2023, inviting all ESO staff. This event aimed to reflect on the remarkable achievements of the VLT in scientific, technical, operational, logistic, and human aspects throughout these two and a half decades of teamwork. For this occasion, a group of ESO Students and Fellows on both sides of the Atlantic teamed up with ESO staff astronomers and science visitors to present the evolution and state of the art of nine different science topics included in the time capsule: the Galactic centre, exoplanets, degenerate stars, distant supernovae, microlensing, chemical evolution of the Galactic disc, galactic X-ray sources, gravitational lensing and nearby radio galaxies.

In addition, experts in lasers and adaptive optics provided a historical summary of, and a forward look at, one of the most significant technical achievements at the VLT. Live presentations were given from Vitacura, Paranal and Garching on the achievements and current status of VLT Science Operations and Data Flow, respectively. The event commenced with a brief summary of the historical first-light event by the ESO VLT Programme Scientist, the current ESO Director for Science Bruno Leibundgut. The closing remarks from the Director General Xavier Barcons highlighted the significance of the VLT and its leadership position in the context of international astronomy. He emphasised the human aspect, the contribution of logistics and administration, the international cooperation needed to make the programme a reality, the operational model, data flow, technical development, cutting-edge instrumentation, and continuous updates that have made

Figure 1. A lot can change in more than two decades — just take a look at these pictures of ESO's Very Large Telescope (VLT)! On the left we see the VLT when it was still under construction atop Cerro Paranal in Chile, while on the right we see it in all its glory as it stands today.

the VLT one of the most productive telescopes on Earth.

The VLT's remarkable contribution to science through superb instruments

More than three decades ago the discovery of the first Type Ia supernova at high redshift ($z = 0.31$) with the Danish 1.5-metre telescope on La Silla was reported in the journal Nature. These supernovae, identified as standard candles for estimating cosmological distances, have been extensively studied with the VLT. In 2011 the Nobel Prize in Physics was awarded "*for the discovery of the accelerating expansion of the Universe through observations of distant supernovae,*" in which the 8.2-metre VLT telescopes at Paranal, the 3.6-metre and the New Technology Telescope (NTT) on La Silla and ESO staff played a major role.

Observations of the proper motions of stars near the centre of the Milky Way have provided evidence in recent decades for the existence of a supermassive black hole at the Galactic centre. Over the course of 26 years, observations carried out with sensitive instruments at the NTT at La Silla and at Paranal, such as the Nasmyth Adaptive Optics System – COudé Near-Infrared CAmera combination (NAOS–CONICA, or NACO) and the Spectrograph for INtegral Field Observations in the Near-Infrared (SINFONI) at the VLT, and the GRAVITY instrument at the VLT Interferometer, contributed significantly to the Nobel Prize in Physics in 2020. These observations, including 16 years of tracking stars orbiting Sagittarius A*, provided empirical evidence for the existence of the supermassive black hole at the centre of our galaxy. GRAVITY has been fundamental in studying at high-precision orbits of stars near Sagittarius A* and testing general relativity, providing images 20 times sharper than those from individual VLT telescopes.

The VLT has played a leading role in the direct detection and characterisation of exoplanets. In 2004 the adaptive optics-supported NACO facility provided the first image of a planet outside our Solar System. To date more than 5000 exoplanets have been discovered and there are over 4000 known planetary systems.

Figure 2. This splendid colour image of a famous southern Planetary Nebula, NGC 6302 or the Bug Nebula (sometimes nicknamed the Butterfly Nebula), was obtained by combining blue, yellow and red images obtained on May 22, 1998, with 10 minute exposures and an image quality better than 0.6 arcseconds.

Instruments like the Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE) have revealed a variety of exoplanet architectures, including the first-ever image of two planets orbiting a Sun-like star. The new Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO) instrument is focused on determining the composition of exoplanet atmospheres, paving the way for future studies with ESO's Extremely Large Telescope (ELT). The combined capabilities of the VLT and the Atacama Large Millimeter/submillimeter Array (ALMA), in which ESO is a partner, and the forthcoming ELT, will make ESO a unique observatory with the ability to study the formation and evolution of planets and their atmospheres in unprecedented detail.

Entering the era of gravitational wave astronomy, multi-epoch data from the Fibre Large Array Multi Element Spectrograph (FLAMES) enabled the discovery of a stellar-mass black hole in the Large Magellanic Cloud. In 2017 ESO's telescopes, including the VLT, characterised the first visible counterpart of a gravitational wave source.

Advanced engineering systems: adaptive optics and laser guides at the VLT

The technology of the VLT has been continuously adapted and improved. The VLT Interferometer employs larger individual telescopes than any such instrument anywhere in the world and combines the light from them better. New instruments have provided new observing capabilities and the facility has grown to include adaptive optics with natural guide stars and artificial stars created by powerful laser beams.

ESO has remained at the forefront of adaptive optics and laser guide star technologies in astronomy for the past three decades. The adaptive optics technique plays a crucial role in correcting the distortions introduced by atmospheric turbulence in real time, rapidly adapting the mirror shape to counteract the blurring effect caused by the atmosphere. To achieve this, a bright star close to the astronomical target is required as a reference. However, such bright stars may not always be available in the vicinity, necessitating the creation of 'artificial' stars using lasers.

By exciting sodium atoms in the mesosphere, approximately 90 kilometres above Earth's surface, lasers generate artificial stars. Initial experiments in this area commenced in 1998, with the first light of the single laser guide star in UT4 in 2006. In 2016 the VLT further enhanced its Adaptive Optics Facility by installing the 4 Laser Guide Star Facility, each laser producing 22 Watts of power. This cutting-edge facility will serve as a crucial testbed for the ELT, which represents ESO's next major astronomical endeavour and which is already halfway through its completion process.

Operations model and end-to-end data flow

Science operations have played a crucial role in the success of the VLT. Over 25 years the facilities have continuously evolved, requiring the management of three different generations of instruments at the observatory, all adhering to the highest standards. As complexity has increased over time, science operations have adapted to new needs and circumstances, including the challenges posed by the COVID-19 outbreak, which led to the only long-term suspension of science operations at Paranal in 25 years.

The VLT Data Flow System effectively manages the complexity of handling multiple instruments and observing modes. This closed-loop software system consists of various subsystems that ensure a smooth flow of data, from proposal submission by scientists all the way to the final storage of the collected data in the ESO Science Archive Facility.

The remarkable achievements of the VLT over the past 25 years were the result of the team spirit, dedication, and international collaboration at ESO. Together, we have pushed the boundaries of astronomical exploration. As we look to the future with the construction of the ELT, the enhancement and future development of ALMA and another suite of new instruments for the VLT, exciting times lie ahead, which will ensure the success of ESO as a world-leading observatory.

References

Giacconi, R. 1997, The Messenger 87, 1

Links

[1] ESO Time Capsule Press Release: https://www.eso.org/public/news/eso9710/
[2] VLT 25th anniversary Announcement: https://www.eso.org/public/announcements/ann23009/

This photograph captures the Unit Telescope 4 of ESO's Very Large Telescope, located in Chile's Atacama Desert, and its four-laser system, which is used to excite sodium atoms in the atmosphere. The atoms excited by the lasers emit light that is affected by the atmosphere in the same way as the light emitted by real stars. The emitted light is collected by the telescope and can be used by the adaptive-optics system to measure the distortions introduced by the atmosphere and then to correct for them. This advanced system, combined with the excellent dark-sky conditions of the Atacama Desert, ensure the telescope can obtain extremely sharp images.