

Report on the EAS Symposium

ESO@60: A stairway to the Universe

A Symposium to celebrate ESO's 60th anniversary, held at EAS2022 in Valencia, Spain on 30 June–1 July 2022

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The symposium ESO@60: a stairway to the Universe was held during the European Astronomical Society (EAS) annual meeting in Valencia, Spain, in June 2022. The focus of the symposium was on the scientific achievements with ESO facilities over the last 60 years. The programme consisted of six sessions of 1.5 hours each. Each session covered a broad theme: Extrasolar Planets, Astrochemistry and Nucleosynthesis, Stellar Populations and Star Formation, Black Holes, Cosmology and Galaxy Evolution, and a Look Ahead to ESO's Extremely Large Telescope and the next decade. Eight keynote speakers introduced their topics by highlighting how the ESO facilities and their operations, including the end-to-end dataflow system and the ESO Science Archive Facility, contributed to the scientific advancements in their specific areas. The current and two former ESO Director Generals, namely Xavier Barcons, Catherine Cesarsky and Harry van der Laan, attended the symposium and participated in the lively discussions.

From an idea by visionary European astronomers in the 1950s, and the signing of the ESO Convention on 5 October 1962^a, today ESO is the world's most productive ground-based observatory, with over 19 000 refereed publications based on data acquired with its facilities. ESO operates the La Silla Paranal Observatory, hosting some of the world's largest and most advanced observational facilities at three sites in Northern Chile: La Silla, Paranal and Chajnantor^b. Furthermore, these ESO facilities have contributed to major scientific discoveries, such as the accelerated expansion of the Universe, the existence of black holes, the detection and characterisation of exoplanets, the formation and evolution of stars and planets, and the history of galaxies. Realising the vision of its founders, ESO has fostered and supported the ingenuity and

scientific creativity of the scientists in its Member States. The scientific organising committee (SOC) of the ESO@60: a stairway to the Universe symposium was composed of ESO astronomers and Council members. The SOC members were the current ESO Director General Xavier Barcons (ESO), ESO Council President Linda Tacconi (Max Planck Institute for Extraterrestrial Physics, Garching, Germany), Amina Helmi (Kapteyn Astronomical Institute, Groningen, the Netherlands), Rob Ivison (ESO), Antoine Mérand (ESO), Michele Cirasuolo (ESO), Paola Andreani (ESO), and Francisca Kemper (ESO) and it was co-chaired by Magda Arnaboldi, Carlos De Breuck and Bruno Leibundgut, all from ESO.

The symposium programme¹ consisted of six sessions, each covering a broad theme: Extrasolar Planets, Astrochemistry and Nucleosynthesis, Stellar Populations and Star Formation, Black Holes, Cosmology and Galaxy Evolution, and a Look Ahead to ESO's Extremely Large Telescope and the next decade. Following a keynote introductory talk, each session then led on to the scientific highlights in cutting-edge research being pursued by exciting and challenging ongoing observing programmes. Presentations featured contributions from the PIs on the scientific achievements of the ESO public surveys, both imaging with the Visible and Infrared Survey Telescope for Astronomy (VISTA) and the Very Large Telescope (VLT) Survey Telescope (VST), and spectroscopic. These were complemented by contributions from community members who had accessed the published public survey science data products via the ESO archive for their own independent science. From the scientific achievements with ESO facilities over the last 60 years, the programme moved on to a forward look at the next technological challenges and discoveries. The discussion of future endeavours included the next big eye on the sky, ESO's Extremely Large Telescope (ELT) with its 39-meter-diameter mirror, its operations and dataflow, and its synergies with other facilities, including those at ESO, such as the Atacama Large Millimeter/submillimeter Array (ALMA) and, in the near future, the Cherenkov Telescope Array (CTA), and worldwide, such as the JWST, Euclid and Vera C. Rubin Observatory.

The first session of the symposium was on the subject of stellar populations and star formation. The first talks illustrated the results from some ESO public surveys: the Gaia-ESO survey (spectroscopic; PIs Gilmore & Randich) and the VISTA Variables in the Via Lactea surveys (VVV and VVVX) (VISTA imaging; PIs Minniti & Lucas) which are dedicated to the exploration of the physical properties of the Milky Way galaxy components and the inner 3D structure of the Milky Way, including the Galactic bulge, bar and halo. These talks highlighted the scientific results on the metallicity gradients in the Milky Way disc and the peanut-bulge structure of the inner bar and bulge in the Milky Way, including the constraint on the angular speed of the bar from the VVV proper motions. The presentation about the VPHAS+ survey (PI Drew), including the narrow-band H α imaging, presented improved calibrations and stunning images of the ionised gas and planetary nebulae in the disc of the Milky Way. These contributions emphasised the very important synergies with the Gaia mission and benefits of combining ground-based data with the extended Gaia DR3 data release (published in the middle of June). Both ground- and space-based facilities are working together to provide a new updated cartography of the Milky Way. Contributed talks by Angela Bragaglia, Eleonora Fiorellino, Gabriella Zsidi and Agnes Kospal focused on specific Milky Way objects and star formation tracers in the Milky Way, based on new observations in the optical and near-infrared (NIR) and with ALMA, together with archival data.

The second session turned to astrochemistry and nucleosynthesis. The keynote speaker, Paola Caselli, presented the latest developments in this area, which span from the biochemistry in the pre-stellar cores to extrasolar planets and life. Caselli presented the evidence for complex molecules in the densest molecular clouds in the Milky Way interstellar medium, where the first stages of star and planet formation take place, how the two are intimately related and how dust grains covered with ice are effective transporters of highly complex molecular species. Very important was the illustration of near-infrared spectroscopy, with ISAAC, and also high resolution, with

CRIFES, along with the synergies with ALMA, both spectra and imaging, illustrated by the inspiring image of the protoplanetary disc of HL Tauri². Caselli also set the stage for optical interferometry as a new observing technique to help in the quest to discover and identify rocky planets in the habitable zone around nearby stars. The keynote talk was followed by a presentation by Nic Cox on the ESO Diffuse Interstellar Bands Large Exploration Survey (EDIBLES).

In the cosmology and galaxy evolution session, Françoise Combes, winner of the 2021 L'Oréal women for science

Figure 1. Visual summary of the world-leading facilities in which ESO participates or which will be operated by ESO.

international prize, presented the properties and evolution of the star formation and baryonic cycle. Her talk covered the interplay of gas and stars in galaxies as a function of redshift, the extended gas distribution around galaxies, cooling flows and the morphological transformations triggered by hot gas in high density environments. Combes illustrated the advances made possible by the use of VLT instruments working in the optical (MUSE) and the NIR (KMOS, SINFONI, and NACO) along with Hubble Space Telescope imaging and ALMA to map and resolve the inflow, outflow and kinematics of ionised gas in high-redshift objects. The synthesis of these multi-wavelength (from optical/UV to submillimetre and millimetre wavelengths) and multi-spatial-resolution observations showed that the molecular

gas fraction was much higher in the past, and that galaxies were baryon-dominated. The circumgalactic medium around galaxies at distances larger than 30–50 kpc is now detected in emission lines, for example Ly α , (C I) and CO, which are excited by starbursts and active galactic nuclei, mostly by outflows. Cooling flows and wakes are seen in X-rays in cluster cores when the brightest cluster galaxy is in motion with respect to the barycenter of these large-scale structures, and molecules form in the filaments. Finally, mapping of CO molecular submillimetre emission showed the formation of molecular filaments along with H α emission via tides and ram-pressure from galaxies in clusters. This keynote talk set the stage for a vibrant overview of the ESO public extragalactic surveys and Large



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Programmes that aim at constraining the time evolution of galaxies and their complex morphologies. The contributions in this session included a presentation on the Large and Small Magellanic Clouds from the VISTA Magellanic Clouds (VMC) public survey (PI Cioni), the extended photometry of galaxies in the nearby Universe (VEGAS project, PI Iodice) and the study of barred galaxies (TIMER project, PI Gadotti). The wide-area survey SHARKS (PI Dannerbauer) in the NIR and the VST ATLAS survey (PI Shanks) in the optical are aiming to study the evolution of galaxies and the baryonic acoustic oscillations: indeed, they are carrying out preparatory work that will support the efforts by the international community with both the Euclid mission and the Legacy Survey of Space and Time.

On the spectroscopic side, including both integral-field and multi-object spectrographs, there were contributions by Francesco Belfiore and Annie Hughes from the PHANGS Large Programme (PI Schinnerer) on MUSE and ALMA on the physical properties of discs, and the LEGA-C (PI van der Wel) spectroscopic public survey which is aimed at studying the kinematics of passive galaxies at redshifts 0.6–1.0. The lively discussion was supported by the presentations from PIs and Co-Is and also from active members of the community (talks by Sara Mascia, Michele Morescu and Nicola Borghi) that made use of the publicly available survey data for their independent research. Dialogue between survey teams and community members generated a constructive exchange of views and results. Such lively discussion was a testimony to the legacy value and the success of the ESO science policies to manage public surveys on behalf of the community.

The other two scientific topics covered in the symposium were extrasolar planets, and black holes in galaxies and their roles as seeds for galaxy formation. The extrasolar planets topic was introduced by Didier Queloz, Nobel Prize laureate in 2019. The search for, and observational results on, extrasolar planets feature prominently in ESO's top ten discoveries. This list includes, among other things, the discovery of a rocky planet in the habitable zone around Proxima Cen, the ALMA image of HL Tauri², and the direct

measurements of exoplanet spectra and their atmospheres. Queloz built a narrative around the early phases of this quest, which began with measuring Doppler shifts of nearby stars, leading on to more sophisticated observational techniques which culminated in the images from the GRAVITY instrument on the VLT that show a planet orbiting around a bright star at a distance of about 20 au. This research has produced ground-breaking results by utilising networks of telescopes, from the small, to observe planet transits and identify candidates, to 4-metre telescopes, to make radial velocity measurements, all the way up to the 8-metre VLT to carry out interferometry, high-precision and very-high-resolution spectroscopy with ESPRESSO, leading to the detection of rocky planets and their atmospheres. This field of research also makes use of synergies between space observations (with Corot, Kepler, NASA's Transiting Exoplanet Survey Satellite [TESS] and in future with the ESA space mission PLAnetary Transits and Oscillations of stars [PLATO]) and ground-based data (with ESO's La Silla Paranal Observatory and ALMA). The next milestone, the image of the faint blue dot around another star, is one of the science drivers for the ELT. The keynote talk was followed by a contribution from Basmah Riaz on accretion onto, and outflow from, proto-brown-dwarfs.

Violette Impellizzeri gave the keynote talk on black holes in galaxies and their roles as seeds for galaxy formation. Supermassive black holes play a dual role in galaxy evolution, responsible for feedback that can be either negative or positive. Their outflows are believed to be one mechanism that quenches star formation effectively in giant/active galaxies at the cores of clusters, while at the same time triggering star formation under different conditions. Observations in the optical and NIR have been crucial to unmasking the engine powering the active galactic nucleus hidden behind a torus of dust at the centre of most galaxies. Impellizzeri shared the impressive images of the black hole shadows obtained with the Event Horizon Telescope (EHT). Both ALMA and the Atacama Pathfinder EXperiment (APEX) contributed to the VLBI interferometric observations of the radio emissions from the inner regions of the accretion discs

around the black hole at the centre of M87 in the Virgo cluster and that around Sgr A*. The ALMA data in the centre of the Milky Way have been a game changer, increasing the sensitivity to the level needed to be able to image the black hole shadow. The EHT images produced for the supermassive black holes in M87 and the Milky Way dominated the attention of the astronomical community, as well as the wider public, following the release of these images during press conferences at the European Commission in Brussels on 10 April 2019³ and at ESO on 12 May 2022⁴. Impellizzeri concluded her talk by stating that we are now able to detect gas, jets and molecular outflows around supermassive black holes on large angular scales, and the next challenge is to trace the physical links between the two. Also in this session, Nial Tanvir, PI of the VISTA public survey VINROUGE, explored the connection between merging binary neutron stars and black holes, their relation to gravitational waves and the electromagnetic echos of kilonovae.

The session entitled 'Looking ahead: the next decade' began with a keynote talk by Joe Liske. In his extensive overview of the developments at ESO, Liske touched upon the strategy of the organisation for the 2020s and the science priorities, before moving on to the construction of the ELT and the instrumentation plan. He presented a summary of the La Silla Paranal instrumentation with the VLT instrumentation road maps.

Liske began by illustrating ESO's organisational strengths — world-leading facilities, the ability to support a wide set of science cases, its status as an international & intergovernmental organisation (hence stability, including funding), a successful instrument building model and a reliable platform for hosting national/institution facility-visitor instruments. He then described the efficient operations model and the collaboration with the community over the advanced data products, including those coming from the public surveys. Key aspects of ESO are the highly skilled workforce and the student and fellowship programmes, which function as "a convective zone between ESO and its scientific community" (to quote from the presentation). In his talk, Liske drew on the

ESO Strategy for the 2020s (Waelkens et al., 2021). The science priorities for the La Silla Paranal Observatories (operations and instrumentation) lead towards the ELT. A huge amount of construction activity, both in Europe and on site, is contributing to realising the world’s largest optical-IR telescope, with its 39-meter main mirror. First light is planned for 2027 according to the current management projection. The instrumentation plan for the ELT includes MICADO with the adaptive optics module MORFEO, HARMONI with LTAO and METIS at first light. MICADO is a NIR wide-field MCAO imager (PI R. Davies) and HARMONI is the optical and NIR AO-assisted IFU (PI N. Thatte). METIS adds a mid-infrared imaging and spectroscopy capability. To guide the operation of this incredibly complex machine and its instrumentation, working groups are now in place that bring together expertise from the community, instrument consortia and ESO. On the La Silla Paranal Observatory instrumentation, the current count, including near-future instruments, is 16. With the focus on the unique strengths of the VLT Interferometer (VLTI), the coming years will witness the commissioning/ construction of ERIS, MOONS and 4MOST on Paranal, and NIRPS and SoXS on La Silla. Liske ended his presentation with a look at the current challenges, including the international environment crisis, but then also asking the question whether the VLT model (instrument building, time allocation, operations etc.) scales well to the ELT. Finally the integration of CTA-South and the next big project... clearly food for thought and plans.

Joe Liske’s talk was followed by contributions from Michael Sterzik and Martino Romaniello, on the operations and the dataflow at ESO. Their emphasis was on how the integrated operation model and data flow will be able to scale to the ELT. See Figure 1 for a visual summary of the world-leading facilities in which ESO participates or that are operated by ESO. On the topic of data management, the new developments at ESO, from quality control, pipeline processing to the generation of science data products, were presented by Martino Romaniello, along with the increased legacy content of the ESO science archive facility. In short, a big push from the raw data to science.



The talk by Guy Perrin illustrated the amazing prospect of optical interferometry with the VLTI and both the impact and opportunity of GRAVITY, not only in respect of observations of Sgr A* but also other science cases, including the ‘live’ observation of extrasolar planets. Roberta

Zanin, project scientist for the CTA Observatory, introduced very-high-energy gamma-ray astronomy with the imaging atmospheric Cherenkov technique. The CTA array utilises three different telescope designs to cover a large energy range of gamma rays from

20 to 100 GeV. The CTA telescope time allocation will be driven by standard proposals, and long and large proposals (including Key Science Projects), which will be evaluated on scientific merit. The CTA Observatory is integrated in the ESO programme with 10% of the time on CTA, North and South, available to the ESO community. This creates an exciting opportunity for the multi-messenger/multi-wavelength era.

The concluding remarks of the looking ahead session made it clear that ESO is an organisation that operates world-leading facilities at the La Silla Paranal Observatory and ALMA (together with its international partners) and will do so in the future with ESO's ELT and CTA-South, which calls for the best ESO ever. There are exciting prospects for synergies with space missions, including the JWST, Euclid, Gaia and planet-hunting missions (PLATO, ARIEL) so the future is bright, and we look forward to ESO's next 60 years.

Demographics

The Symposium S14@EAS2022 achieved a good gender balance in both SOC members and keynote speakers with 45% and 50% of females, respectively.

Acknowledgements

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References

Waelkens, C. et al. 2021, *The Messenger*, 183, 3

Links

¹ Symposium programme: <https://eas.unige.ch/EAS2022/session.jsp?id=S14>

² ESO Press Release on HL Tauri: <https://www.eso.org/public/news/eso1436/>

³ ESO Press Release on M87 black hole: <https://www.eso.org/public/news/eso1907/>

⁴ ESO Press Release on SgrA black hole: <https://www.eso.org/public/news/eso2208-ehm-mw/>

Notes

^a On 5 October 1962 a Convention was signed in Paris between Belgium, France, Germany, the Netherlands and Sweden to establish the European Organisation for Astronomical Research in the Southern Hemisphere (ESO). Subsequently, Denmark (1967), Switzerland and Italy (1982) joined the organisation. The number of Member States has increased since then, and now sixteen states are full Member States of ESO.

^b The Very Large Telescope at Cerro Paranal is ESO's premier site for observations in visible and infrared light. All four unit telescopes of 8.2 metres diameter are in operation with a large collection of instruments. On La Silla, ESO operates two major telescopes (the 3.6-metre telescope and the New Technology Telescope). They are equipped with state-of-the-art instruments built either by ESO or by external consortia with substantial contributions from ESO. ALMA is a partnership of ESO (representing its Member States), NSF (USA) and NINS (Japan), together with NRC (Canada), MOST and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile.



This picture of the nearby galaxy NGC 6744 was taken with the Wide Field Imager on the MPG/ESO 2.2-metre telescope at La Silla. The large spiral galaxy is similar to the Milky Way, making this image look like a picture postcard of our own galaxy sent from extragalactic space. The picture was created from exposures taken through four different filters that passed blue, yellow-green, and red light, and the glow coming from hydrogen gas. These are shown in this picture as blue, green, orange and red, respectively.