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Report on the ESO workshop

Disks and Planets across ESO Facilities

held at ESO Headquarters, Garching, Germany, 28 November – 2 December 2022

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The observation of protoplanetary discs and exoplanets is a relatively recent and rapidly evolving research field. Many questions are still being posed, driven by both observations and theoretical developments. Discs and exoplanets now constitute a central observational field in astrophysics, and one of the main motivations for ESO and its community to build the Atacama Large Millimeter/submillimeter Array and the Extremely Large Telescope. They are also behind many recent and future developments at the Paranal and La Silla observatories. A workshop was held at ESO Headquarters in November/December 2022 to reflect on the role of ESO facilities (present and future) in this landscape.

Introduction

Observations of protoplanetary discs and exoplanets have always profited from progress in observational techniques: spectroscopic and photometric stability, high-contrast and high-resolution imaging, interferometry in the infrared and submillimetre and so on. ESO facilities played a key role in early observations of discs and planets. In 1996, newly available infrared sensors behind a coronagraph and adaptive optics on the 3.6-metre telescope allowed the first images of beta Pic and its disc[1]. ESO has been at the forefront of large-scale searches for exoplanets by velocimetry with the High Accuracy Radial velocity Planet Searcher (HARPS) since 2003 (Pepe et al., 2004), and with the Echelle Spectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO) since 2018 (Nielsen & Seidel, 2022). The first direct image of an exoplanet was obtained by the Nasmyth Adaptive Optics System – COudé Near-Infrared CAmera combination (NACO) at the Very Large Telescope (VLT) in 2005[2], followed by several more, recently with the Spectro-Polarimetric High-contrast REsearch instrument (SPHERE). One of the landmark results of the Atacama Large Millimeter/submillimeter Array (ALMA) was the stunning image of the dusty disc around HL Tau[3] in 2014, revealing unexpected ring structures that were interpreted as a signature of ongoing planet formation (ALMA Partnership, 2015).

Beyond these historical achievements, what is the future of observations of discs and planets using ESO facilities? What are the latest theoretical developments? How can they be addressed observationally? How are ESO facilities transitioning from making the first discoveries to surveying large populations? What are the latest observational techniques? How do ESO facilities play against and/or complement other facilities? What does the near future hold, in particular with the Extremely Large Telescope (ELT) on the horizon?

Following a recommendation by the Scientific Technical Committee (STC), the four ESO programme scientists (for the ELT, ALMA, the VLT and the VLT Interferometer) organised the workshop Disks and Planets across ESO Facilities[4] held at ESO's Headquarters from 28 November to 2 December 2022, in order to address these questions and invite community contributions. The workshop was organised in eight half-day sessions, each consisting of an invited review, contributed talks and a moderated discussion. The workshop focused on the following topics: Protoplanetary discs and evolution; Disc chemistry; Protoplanet detection; Planet atmospheres; Planet detection; Biosignatures; ESO opportunities; and Synergies with space missions.

The workshop showed that the community is currently in a privileged situation with access to a unique infrastructure for ground-based astronomy at the global level with facilities like ALMA, the VLT, the VLT Interferometer (VLTI) and the ELT. ALMA has revolutionised the study of discs in the submillimetre by improving by an order of magnitude or more the sensitivity and angular resolution of disc images. Since the first stunning image of gaps in the HL Tau disc, ALMA has provided insights into the architecture of gas and dust interaction. Understanding these observations is still an active research topic. The new frontiers lie in multi-band studies and increasing the sample of observed discs. Future directions require larger samples: expanding to fainter discs, more compact ones (where the dust has settled inwards) or discs in star-forming regions with more common environmental conditions. This requires more observing time via community organisation of surveys, as well as higher sensitivity (which is in part covered by the ALMA2030 development plan[5]) and higher angular resolution.

Protoplanets are hard to find because they are embedded in the discs. Only the exceptional case of PDS 70, where the protoplanets lie in an inner cavity, provides an observational example of interplay between the disc and the forming planets. This system has been discovered and observed by many ESO facilities: SPHERE, NACO, the Multi Unit Spectroscopic Explorer (MUSE; at the VLT), and GRAVITY (at the VLTI), as well as with ALMA, showcasing the suite of instruments ESO provides to its community. A promising technique to detect more protoplanets with ALMA is via perturbations in the Keplerian velocity field of a disc.

Obtaining a complete census of exoplanet demographics requires many observational techniques and facilities beyond even the rich palette offered by ESO. ESO has been at the forefront of planet discovery by radial velocity measurements and direct imaging. Remaining competitive requires observing time for large surveys and/or advances in instrumental technology. The current ESO operational model does not seem to be a limitation as it offers the possibility of large observing programmes and public surveys. The role of ESO facilities as discovery and/or follow-up machines was also discussed: some observations with ESO telescopes can lead to the discovery of discs or planets which can better be characterised by complementary facilities, in particular in space (the JWST, the CHaracterising ExOPlanet Satellite [CHEOPS] etc.) and vice-versa: other facilities (such as Gaia) can provide candidates which can be then observed more deeply with ESO facilities. There is no single recipe and ESO facilities have a significant role to play in both discovery and follow-up.

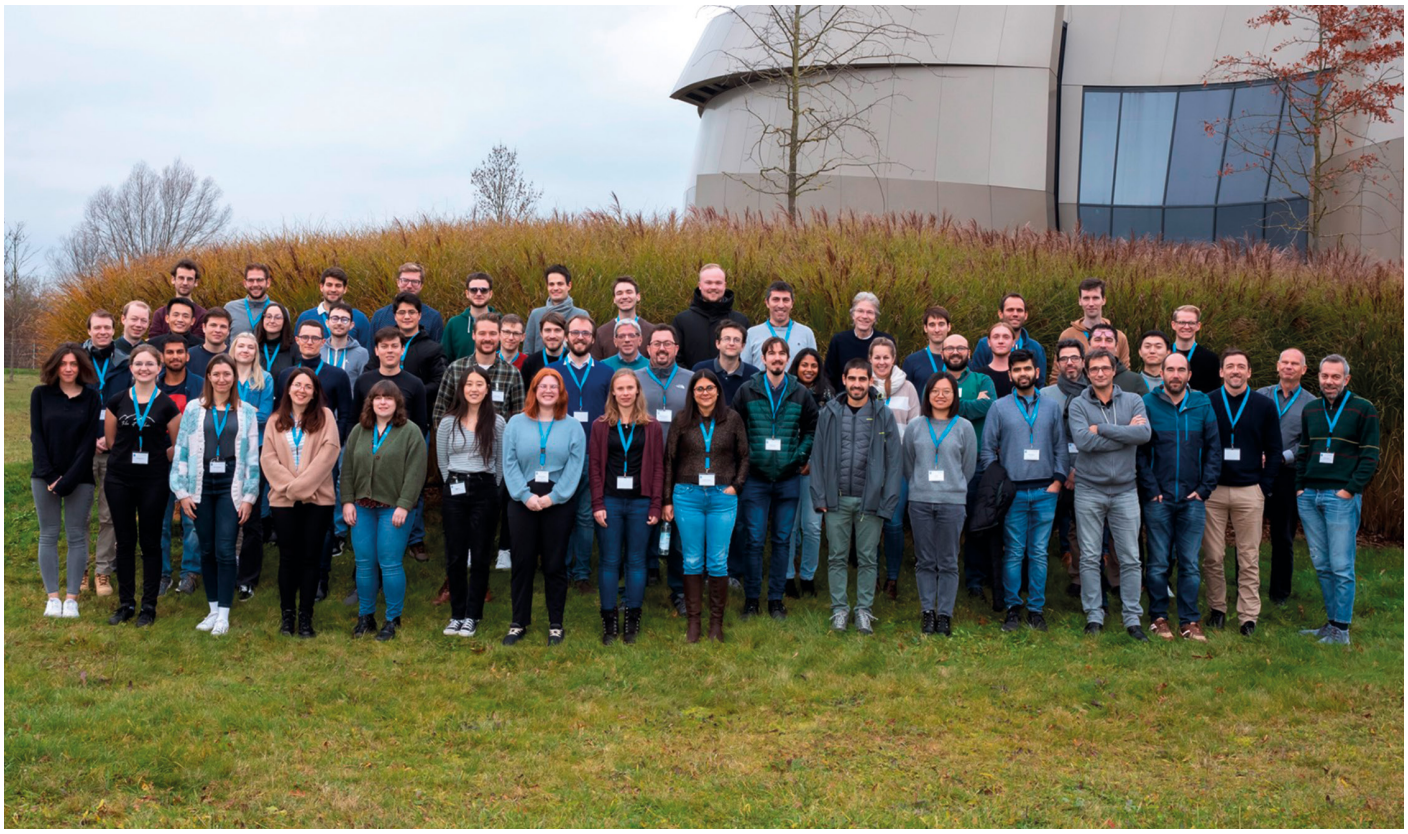

Figure 1. Group photo of the in-person workshop participants.

The search for biosignatures in the atmospheres of temperate rocky exoplanets is a major science driver in astronomy today. This, however, requires very demanding instrumentation. Two main avenues are being pursued: transmission spectroscopy for transiting planets, and spatially-resolved spectroscopy for non-transiting planets. The JWST is currently pushing the limits of transit spectroscopy towards habitable-zone planets, specifically in the TRAPPIST-1 system. Our next-best opportunity will likely come from reflected-light spectroscopy using ground-based instrumentation. Several ideas were proposed to enable the characterisation of the atmospheres and surfaces of habitable-zone planets in the next decade.

Finally, workshop contributions showed that the environment of technological and instrumental developments is a fast growing and rapidly evolving field, particularly in the context of integral-field spectroscopy, high spectral resolution, high-contrast imaging and interferometry. This requires the ability to support upstream critical developments to remain competitive and to prepare the development of ALMA, the VLT/I and particularly the ELT. These elements are already present in current developments (for example, ALMA2030[5] or VLT2030; Mérand & Leibundgut, 2019), and will continue for future exercises.

The workshop took place at ESO Headquarters in Garching, as well as online. The Scientific Organising Committee (SOC) was composed of the four ESO programme scientists and eminent members of the discs and exoplanets communities (including from ESO and the STC). Particular care was taken to balance gender, seniority and geographical origin of the SOC members, the eight invited speakers and the 68 contributors. In all, 135 participants registered and at any given time there were about 100 workshop participants present: 50 people in the conference room (Figure 1) and 50 online (some attendees only participated in the discs or planets sessions).

Acknowledgements

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References

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Nielsen, L. D. & Seidel, J. V. 2022, The Messenger, 187, 8
Pepe, F. et al. 2004, A&A, 423, 385

Links

[1] Beta Pictoris image: https://www.eso.org/public/news/eso9714/
[2] First exoplanet image: https://www.eso.org/public/news/eso0515/
[3] HL Tauri image: https://www.eso.org/public/news/eso1436/
[4] Workshop webpage: https://www.eso.org/sci/meetings/2022/disks_and_planets_at_ESO.html
[5] ALMA Development Roadmap: https://almaobservatory.org/en/publications/the-alma-development-roadmap/