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Report on the ESO Workshop

Ground-based Thermal Infrared Astronomy — Past, Present and Future

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This ESO workshop was originally planned as a traditional in-person meeting at ESO in Garching in April 2020. It was rescheduled and transformed into a fully online event in light of the COVID-19 pandemic. With 337 participants from 36 countries the workshop was a resounding success, demonstrating the wide interest of the astronomical community in the science goals and the toolkit of ground-based thermal infrared (IR) astronomy.

Motivation

Observations in the thermal IR regime (3–30 μm) provide a powerful tool for discovering and characterising warm environments in the Universe, from protoplanetary discs — the building sites of planets, to active galactic nuclei (AGNs) — the surroundings of accreting supermassive black holes. The thermal IR is also the wavelength range of choice in which to peek through exoatmospheric clouds to characterise exoplanet atmospheres. Although space-based instruments offer the ultimate sensitivity, observations from the ground provide unrivalled spatial and spectral resolution. Thanks to regular upgrades, they are also the preferred testbed for new technologies or exciting experiments — as recently demonstrated by the Near Earths in the AlphaCen Region (NEAR) experiment at ESO's Very Large Telescope (VLT) (Kasper et al., 2019).

Astronomers working in the field routinely push instruments to their limits, demanding better sensitivity, stability over longer timescales and higher contrast, all of which ultimately rely on complete instrument characterisation and calibration. This is very relevant for all major astronomical observatories which currently host thermal IR cameras or spectrographs, such as the VLT Imager and Spectrometer for the mid-InfraRed (VISIR), the Multi AperTure mid-Infrared SpectroScopic Experiment (MATISSE) at the VLT Interferometer, and CanariCam at the Gran Telescopio Canarias. Calibration in the thermal IR will be an even more important prerequisite for reaching the ambitious science goals of the next-generation facilities; for example, characterising exoplanets is one of the prime science goals of the Mid-infrared ELT Imager and Spectrograph (METIS), a first-generation instrument for ESO's Extremely Large Telescope (ELT) and of the Mid-IR Camera, High-disperser and IFU spectrograph (MICHI) on the Thirty Meter Telescope (TMT).

The workshop brought together experts to present two complementary types of review talks. Some of the speakers summarised the state of the art in individual fields significantly reliant on observations in the thermal IR, such as Solar System planets, studies of young stellar objects and evolved stars, the centre of the Milky Way galaxy and more distant active and star-forming galaxies. Other speakers presented individual facilities, described their capabilities and paraded the most successful science cases addressed with these instruments. There was also a talk about the history of the field and a diversity and inclusion session. Last but not least, three discussion sessions on topics selected by the participants allowed for a lively exchange of opinions[1].

Lessons from the online workshop format

The workshop was hosted online because of the ongoing COVID-19 pandemic, but also to increase inclusivity and sustainability. Three platforms facilitated communication between the participants during the workshop (Figure 1). Talks and discussion sessions were transmitted live via Zoom. Slack was used to exchange text messages and to post files (for example, PDFs of posters). Gather.town allowed video, audio and text interaction during the virtual coffee breaks, the virtual welcome reception and the dedicated poster viewing session. It was most popular during the poster session; during the breaks the participants preferred to spend time offline. After the conference, two platforms were — and are being — used for distributing content: video recordings of the presentations were placed on YouTube within 24 hours, to allow participants in different time zones to watch them and to participate in the discussions. Most of these talks remain publicly available on our YouTube channel[2]. As of April 2021, still more than four hours of recordings are watched every month. Slides and posters were uploaded to Zenodo[3] to create a permanent record of the workshop that is also indexed by the SAO/NASA ADS service.

The chosen workshop format was very well received by the conference attendees. In our exit survey, answered by a representative subset of 107 participants, about 90% responded that they rate as good or excellent the quality of the talks, the meeting format and the overall experience. We also asked how this workshop compared to traditional in-person meetings and 85% of the respondents said that the legacy value of our online meeting was equally high or (much) higher than that of a traditional meeting. There were mixed reactions, however, to the question about networking aspects. 60% said they had (much) fewer interactions; 40% found the quality of interactions (much) worse. But, a noticeable 22% reported (much) more interactions and 27% reported (much) better quality of interactions. Curiously, this answer depends significantly on the career stage of the researcher. Senior scientists (and to a lesser degree postdocs) were more likely to answer less or lower quality of interactions, while for (PhD and master) students, the situation was reversed. Therefore, at least for our participants, it does not seem to be true that online meetings are particularly harmful for networking aspects of junior researchers.

The online discussion sessions were especially lively, with more than a thousand messages exchanged daily between the participants via Slack. However, having participants in many different time zones proved to be a challenge. Some participants from, for example, the United States or Chile joined the live Zoom sessions in what was for them the middle of the night. Others preferred to watch the talk recordings at a more convenient time; although they were unable to participate fully in the live discussions, Slack helped them to follow up on discussions the next day. Based on our exit survey, there was a clear preference (~ 85% of students, postdocs, and senior scientists alike) for reducing the amount of (synchronous) online time to three to four hours per day for a possible follow-up workshop.

Last but not least, the online format very significantly reduced the carbon footprint of the workshop. If all 337 participants had travelled to Garching, an equivalent of 564 tons of CO_2 would have been emitted. Online conferences — and this one is no exception — are known to reduce emissions by at least a factor of three thousand compared to traditional in-person meetings (Burtscher et al., 2020).

Demographics and inclusion

The workshop was well attended, with 337 registered participants from 36 countries (see Figure 2a). As many as 160 people were online at the same time. For comparison, the typical number of participants for in-person ESO workshops in recent years was 80–120. ESO Member States dominated the demographics with 189 participants (56%); all ESO Member States were represented. Women constituted 33% of the attendees, and the Scientific Organising Committee formulated a scientific programme that reflected this percentage (35% of the contributed talks were delivered by female speakers). A conscious effort was made to increase the fraction of invited female speakers, reaching 39%. The selection of contributed talks was made without considering the gender or country of origin of the applicants. In addition, with 31% students, 23% postdocs and 46% senior researchers, the workshop achieved a good balance of career level and seniority (see Figure 2b) — in fact, it was among our goals to promote the thermal IR field amongst early-career astronomers.

Diversity and inclusion issues in astronomy were addressed specifically during a podium discussion led by Angela Speck in which a number of good practices were recommended. It is often already a good start to simply begin paying more attention to issues of diversity and inclusivity, to use inclusive language, and to be a “good bystander”, for example to intervene when microaggressions[a] happen. The gender balance in astronomy was discussed, as well as specific issues such as the effect of the COVID-19 crisis on gender diversity. In addition, attention was paid to geographic and language barriers, and access by developing nations to the (expensive) infrastructure required to do observational astronomy in the thermal IR.

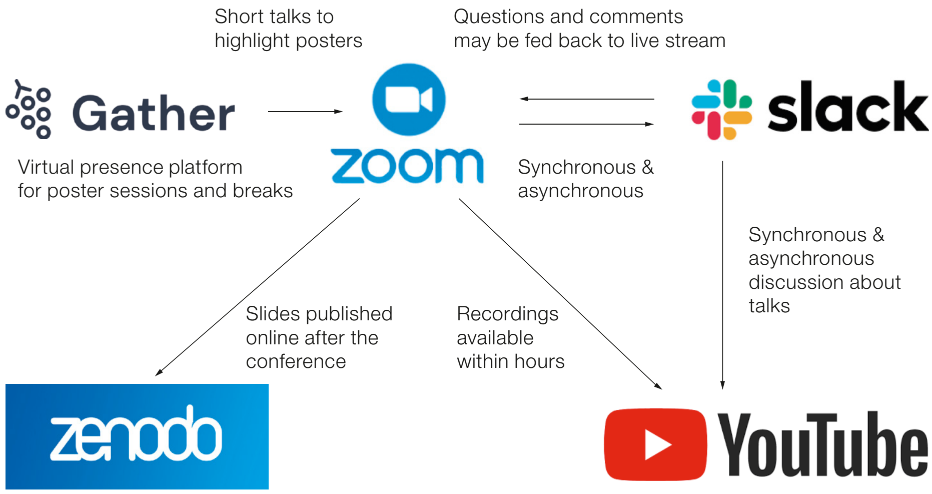

Figure 1. Platforms and services used to organise the online conference.

Science highlights

Over the five days of the workshop a total of 66 talks were given (23 invited, 43 contributed) and 18 online posters were presented, divided into ten scientific areas (Active Galactic Nuclei, Dust/Interstellar Medium, Exoplanets, Galactic Centre, Galaxies, Instruments, Protoplanetary Discs, Solar System, Stars/Circumstellar Environments and Young Stellar Objects). In this short article, we cannot give a comprehensive review of all these fields, but based on a number of both scientifically and visually striking examples, we would like to highlight the diversity of science fields to which ground-based thermal IR astronomy is contributing and how this observing technique provides a unique perspective on these fields. Figure 3a–g illustrate these examples, as follows:

a) Observations of the giant planets from VISIR: Jupiter, Saturn, Uranus, and Neptune (left to right, top to bottom: Fletcher et al., 2017, 2018; Roman et al., 2020; Sinclair et al., 2020). The observations use wider waveband coverage, denser temporal sampling, and more modern technology than available on space probes.
b) VLT/NEAR image of the α Centauri A/B system as observed behind a coronagraphic vortex mask. No planet has been detected in this image, but a detection would have been possible down to ~ 400 μJy, corresponding to a contrast of 3.2×10^{-6} compared to α Cen. A candidate (C1) has been detected that requires follow-up observations for confirmation (Wagner et al., 2021). Ground-based adaptive-optics coronagraphic imaging in the thermal IR has a unique potential to detect faint Earth-like planets at more extreme contrasts than possible from space.
c) A wide-field (~ 5 × 3.5 arcminutes) mosaic of the Orion nebula in the mid-IR showing the Trapezium region to the bottom-left of the centre and the BN/KL complex just above the centre of the image, as well as significant filamentary structure in between. Owing to the requirement to remove the thermal background in a crowded field, the processing of these observations was technically challenging and to the best of our knowledge it represents the widest-angle observation taken in the thermal IR from the ground with a large telescope so far, i.e., it is both wide-angle and high-spatial-resolution (Robberto et al., 2005).
d) Reconstructed image of FS CMa as observed with VLTI/MATISSE. The *L*-band aperture-synthesis image shows the inclined disc of the unclassi-

fied B[e] star FS CMa. One can see the central star and the bright, inner edge of the disc with an angular resolution of about 4 milliarcseconds (the field of view is 60 × 60 milliarcseconds and the wavelength range 3.4–3.8 μm). The north-western disc rim is brighter than the south-eastern one as we are looking directly at the north-western, inner disc rim wall. The inner dust-depleted hole has a size of about 6 × 12 milliarcseconds (Hofmann et al., in preparation). The spatial resolution afforded by VLTI/MATISSE is unequalled by other thermal IR facilities. Only in the thermal IR is the bulk of the disc seen.

e) Deepest image of the Galactic centre at 8.6 μm: ~ 2-hour on-target exposure with VISIR in the PAH1 filter, July 2017; reduction with speckle holography for maximum spatial resolution. Sgr A* itself is undetected since it is confused with the "Sgr A* ridge" at these wavelengths (Schödel et al., in preparation).

f) Stratospheric Observatory For Infrared Astronomy/High-resolution Airborne Wideband Camera Plus (SOFIA/HAWC+) magnetic field lines overlaid on a visible (Hubble Space Telescope, Sloan Digital Sky Survey) image of the nearby prototypical AGN NGC 1068. The image supports the "density wave theory" for how the spiral arms are forced into their iconic shape (Lopez-Rodriguez et al., 2020).

g) Observations of a sample of mid-IR-bright active galaxies showing that the central, AGN-heated dust continuum emission is elongated along the same direction as the polar axis of the AGN, indicated by a green bar that is 100 pc in length. The AGN-heated dust can only be resolved in thermal IR observations from the ground (Asmus, Hönig & Gandhi, 2016; Asmus, 2019).

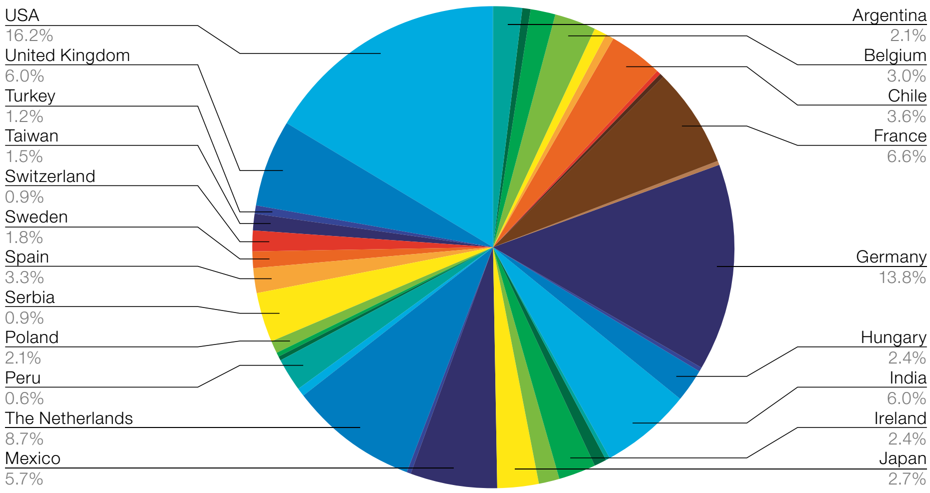

Figure 2a. (Above) Geographic distribution of workshop attendees.

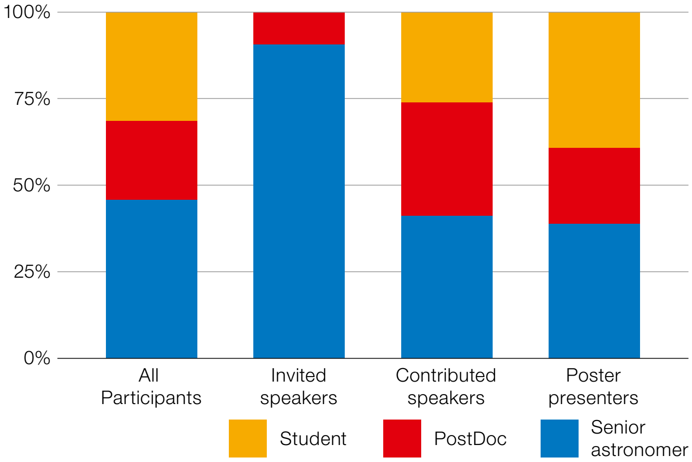

Figure 2b. (Left) Seniority level of workshop participants and presenters.

In addition, three discussion panels were held sequentially and with good and very lively participation from the community. In the first, we asked what the different science areas can learn from each other: for example, can we apply young stellar object (YSO) disc+outflow models to AGNs or evolved stars? We found both similarities (for example, how to link observables to models and which radiative transfer codes to use under which conditions) and differences (for example, the apparent ubiquity of polar-oriented outflows in AGNs was contrasted with the disc morphology of YSOs). The second discussion panel was devoted to instrumentation development and addressed the question of what instrumentation is required in order to pursue our research (and how to get it). In this session we discussed, amongst other suggestions, polarimetry and high spectral resolution in the *N* band (8–13 μm) on extremely large telescopes. The third discussion panel was devoted to community building and investigated what support early career researchers require to enter the field of thermal IR astronomy, in particular whether they need more broad conferences (like this one), a new textbook or more extensive user support (like, for example, the ALMA support nodes). There was agreement among the participants that a follow-up conference in 1–2 years would be useful.

Public outreach event and social media

To further the workshop's goal of promoting awareness of thermal IR astronomy, a public outreach event[4] was held as part of the workshop in collaboration with the Haus der Astronomie in Heidelberg. Nine public talks, given in seven different languages, were streamed live via the Haus der Astronomie's YouTube channel, reaching more than 2500 viewers. The videos are still accessible in their dedicated YouTube playlist[5]. In addition, highlights from the workshop were communicated via the @ESO_IR2020 channel on Twitter, with 155 tweets generating a further 18 900 impressions.

Future outlook

Thermal IR astronomy is entering a new era, both on the ground and in space,

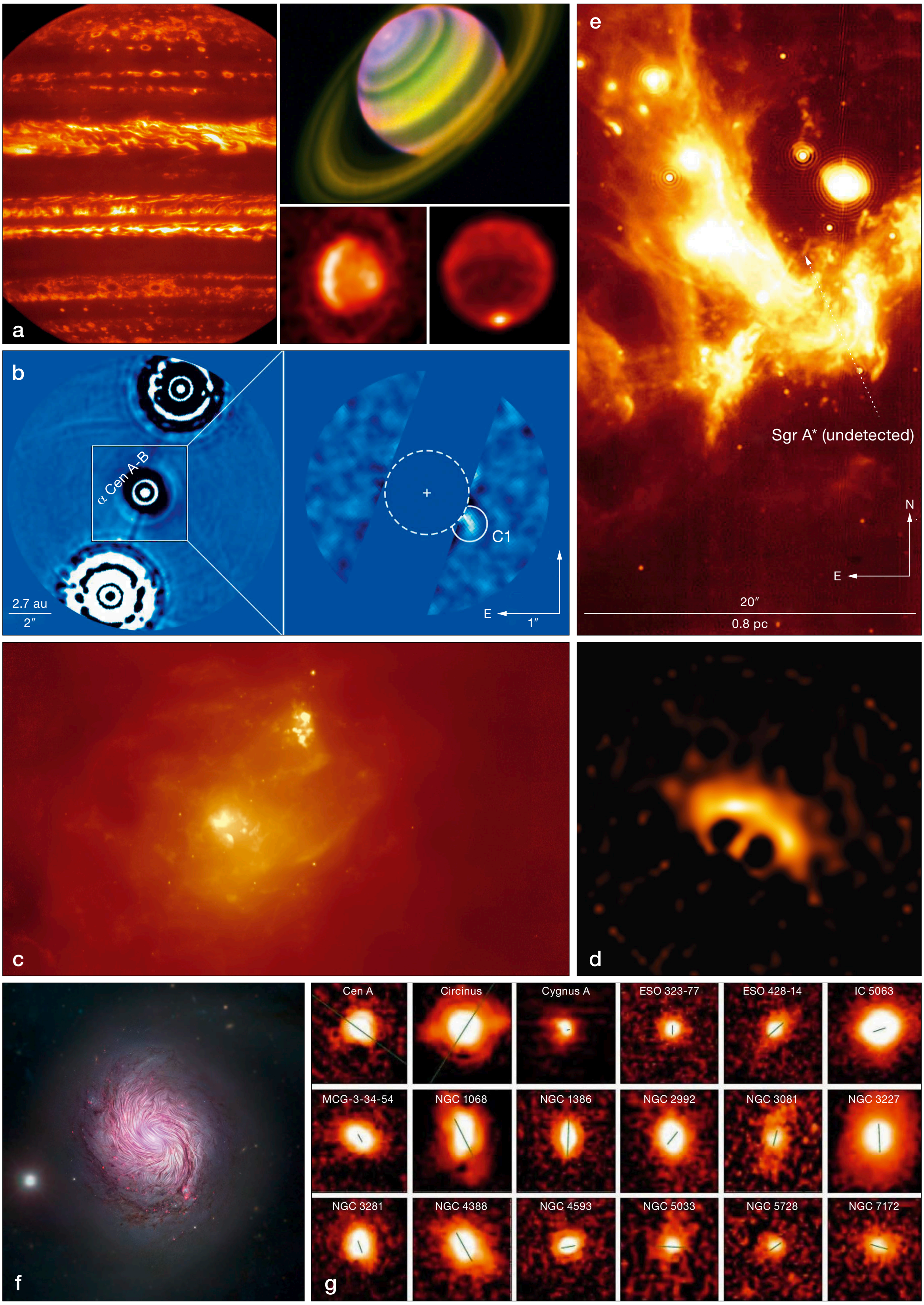

Figure 3. Visual and scientific highlights from ground-based thermal IR observations at large facilities, ordered by distance from the Earth. See text for description.

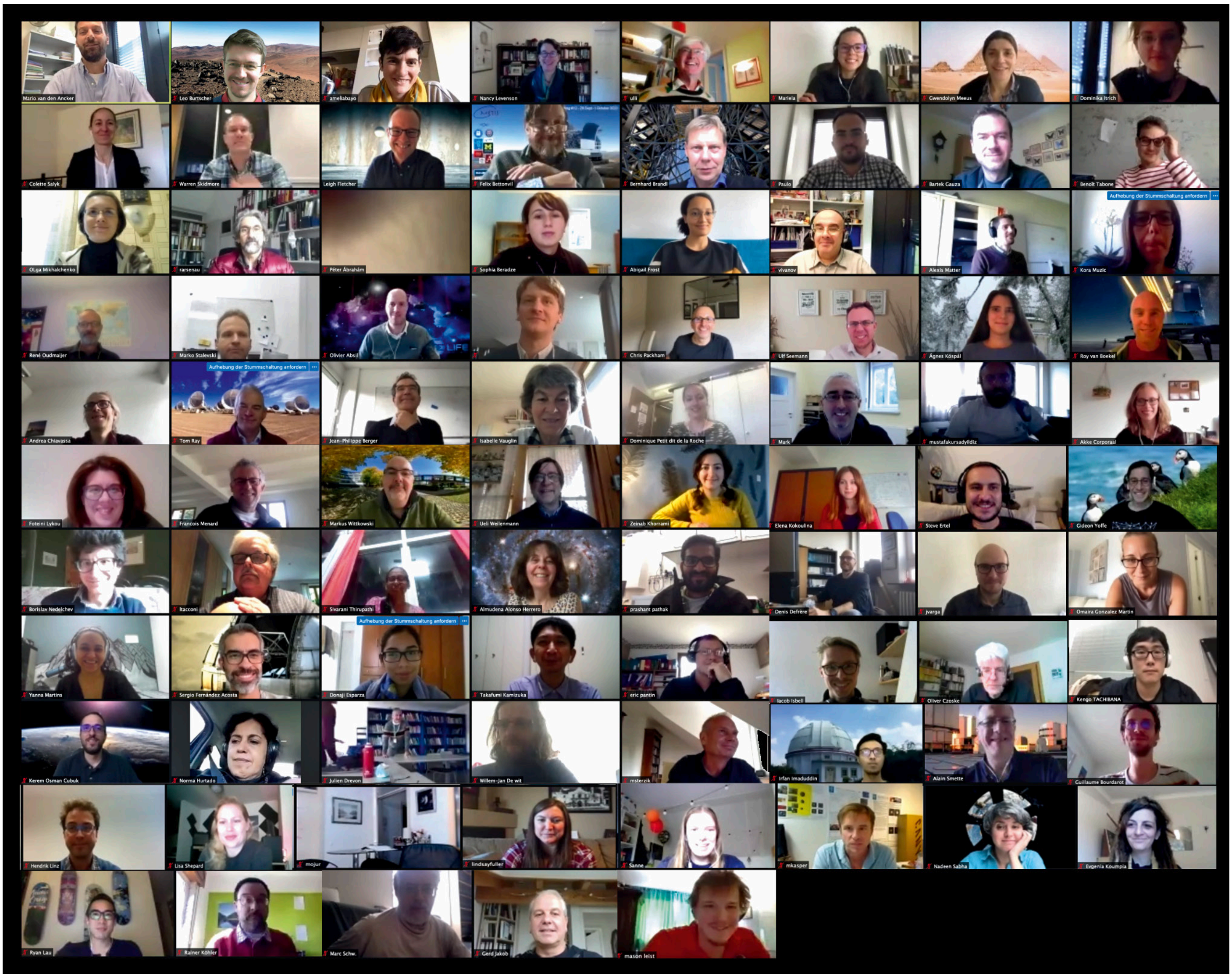

Figure 4. Virtual conference picture showing some of the participants following the live talks.

with the arrival of a number of new facilities. The James Webb Space Telescope is expected to launch later this year. It will provide access to a wavelength range up to 29 μm and will maximise sensitivity thanks to the low thermal background achievable in space. METIS at the ELT is currently expected to see first light in 2028 and will cover the range from 3 to 13 μm, delivering both diffraction-limited imaging at the ELT's resolution of 23 milliarcseconds at 3.5 μm and spectroscopy with resolving powers from a few hundred to a hundred thousand.

A number of innovative smaller instrument projects are also progressing well. For example, the Mid-Infrared Multi-field Imager for gaZing at the UnKnown Universe (MIMIZUKU) at the Tokyo Atacama Observatory (TAO) 6.5-metre telescope at 5640 metres altitude will reach the ultimate (ground-based) transmission, particularly in the challenging *Q* band (~ 20–30 μm). It is planned to upgrade the Mid-InfraRed Array Camera 5 (MIRAC-5) with the novel HgCdTe-based "GeoSnap" detector by Teledyne, possibly a breakthrough in thermal IR detector technology. It will be operated both on the Multiple Mirror Telescope (MMT) and at the Magellan Telescope — both with adaptive optics support — and will pave the way for the use of this novel detector technology in METIS at the ELT and MICHI at the TMT.

Nancy Levenson, in her invited review talk, made the point that the space- and ground-based facilities complement each other in sensitivity, collecting area, cost and rate of technological innovation. She underlined that big facilities serve as natural loci to form active user communities that use the telescopes, but also contribute via various mechanisms — decadal surveys, user committees, etc. — to their planning, development and operation. Our workshop demonstrated the existence of a vibrant thermal IR community (some of whom are seen in Figure 4). The meeting will help to ensure its growth and the inclusion of young astronomers, and to foster close ties amongst the community members for the future. A follow-up workshop is being planned by our Japanese colleagues for early 2022. A decision on the format (fully online or hybrid) is pending.

Acknowledgements

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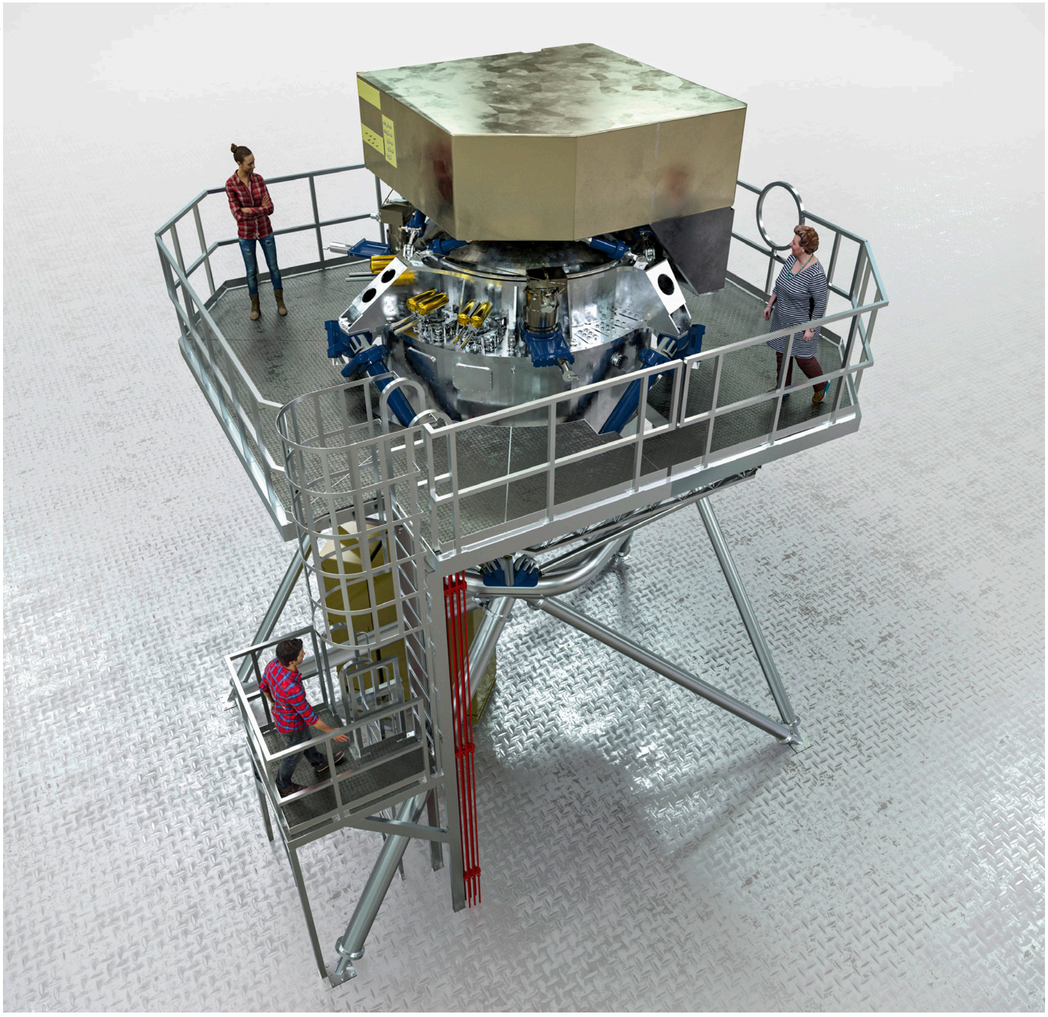
Links

[1] Link to workshop programme: https://www.eso.org/sci/meetings/2020/IR2020/program.html
[2] YouTube channel with recordings of most talks: https://www.youtube.com/channel/UCsTNXi_Sa1j8HQaJAtpmLjg/playlists
[3] Presentations archived at Zenodo: https://zenodo.org/communities/ir2020
[4] Public Outreach Event: https://www.eso.org/sci/meetings/2020/IR2020/public_talks.html
[5] YouTube playlist for the nine public talks organised for the IR 2020 workshop: https://www.youtube.com/playlist?list=PL6v1Ej3QgEXU6L0culH0Imu-_8vpcTSB2

Notes

[a] Microaggression is a statement, action, or incident regarded as an instance of indirect, subtle, or unintentional discrimination against members of a marginalised group such as a racial or ethnic minority.

ESO/METIS Consortium/L. Calçada



METIS, named after the Greek goddess of wisdom, will be one of the first-generation instruments of ESO’s Extremely Large Telescope. It will cover the infrared wavelength range and make full use of the giant, 39-metre main mirror of the telescope to study a wide range of science topics, from objects in our Solar System to distant active galaxies.