Five years of the European Adaptive Optics Summer School

Laura K Young[1], Caroline Kulcsár[2], Karen M Hampson[3], Timothy J Morris[4], Martin J Booth[5], Adam Dubis[6], Enrique J Fernandez[7], Qi Hu[5], Pedro Mecê[8], Serge Meimon[9], Benoit Neichel[10], James Osborn[4], Marinko V Sarunic[6], Matthew J Townson[11], Matthieu Boffety[2], Mamoune Bouanani[2], Sylvie Lebrun[2], Marie-Anne Burcklen[2], Yann Clénet[12], Nicolas Galland[2], Lionel Jacubowiez[2], Inès de Jongh[2], Penelope F Lawton[1], Nicolas Levraud[2], Perrine Lognoné,[4] Irene Papagiannouli[2], Henri-François Raynaud[2], Pablo Artal[7], Timothy Butterley[4], Vincent Chambouleyron[10], Celine d'Orgeville[13], Michael Pircher[14], Andrew P Reeves[4]

[1]*Biosciences Institute, Newcastle University, Newcastle-Upon-Tyne, UK*
[2]*Université Paris-Saclay, Institut d'Optique Graduate School, CNRS, Laboratoire Charles Fabry, Palaiseau, France*
[3]*Department of Optometry, University of Manchester, Manchester, UK*
[4]*Centre for Advanced Instrumentation, Durham University, Durham, UK*
[5]*Department of Engineering Science, University of Oxford, Oxford, UK*
[6]*Institute of Ophthalmology, University College London, London, UK*
[7]Laboratorio de Óptica, Instituto Universitario de Investigación en Óptica y Nanofísica, Campus de Espinardo (Ed. 34), Universidad de Murcia, Murcia, Spain
[8]*Institut Langevin, CNRS, Université PSL, Paris, France*
[9]*DOTA, ONERA, Université Paris-Saclay, Palaiseau, France.*
[10] *Laboratoire d'Astrophysique de Marseille, Aix Marseille Université, CNRS, Marseille, France*
[11]*Department of Mathematics, Physics, and Electrical Engineering, Northumbria University, Newcastle-Upon-Tyne, UK*
[12]*LIRA, Observatoire de Paris, Université PSL, CNRS, Meudon, France*
[13]*Australia Telescope National Facility, CSIRO, Canberra, Australia*
[14]*Center for Medical Physics and Biomedical Engineering, Medical University of Vienna, Vienna, Austria*

Adaptive optics (AO) is developed and used in a range of application areas, from observing microscopic cells to distant galaxies. While the implementation and challenges are different between field, the basic principles of AO are common. In 2019 we began to develop the European Adaptive Optics Summer School with the aim of bringing together students and researchers from across the range of AO domains to learn and develop connections with one another. The first school took place in 2021 and after three years running virtually, we moved to an in-person school with hybrid attendance. This has taken place at the Institut d'Optique Graduate School in Palaiseau, France for the last two years and will be held at the Centre for Advanced Instrumentation (CfAI) in Durham, UK in 2026. This paper presents a summary of the school, both in remote and hybrid format. We describe the motivations for the school, the training provided, and a short analysis of the demographics of the school, and how this has changed over the last five years.

1 Introduction

Adaptive optics (AO), as a concept, was first described by Horace Babcock in 1953 **[1]**. Back then, the technology did not exist to compensate for the "severe limitations imposed upon nearly all astronomical observations by "seeing"". In the 1970's early work began developing the first adaptive optics systems and these were for military purposes. Adaptive optics soon gained the attention of astronomers, who started to develop systems for telescopes, and the technology was eventually declassified in 1991 **[2].** Around the same time, the utility of adaptive optics correction for optical communications also started to be investigated **[3].** The first demonstrations of astronomical adaptive optics systems in the late 80's and early 90's **[4]** were soon followed by work correcting for optical aberrations in the eye with the first closed loop ophthalmic AO system in the mid 90's **[5]**, and by systems compensating for aberrations in confocal microscopy **[6]** in the early 2000's. These developments are reflected in **Fig. 1**, which gives an indication of how the number of publications in each field has developed over time.

Since this early work, AO has expanded rapidly and has found numerous applications beyond these early adoptions. Some of these systems have matured to the point where they can be used by a trained operator who does not have a background in AO, such as telescope operators using facility-class instruments. In fact, a fully automated AO system, RoboAO, has been developed at the University of Hawaii and deployed on a small number of telescopes. In ophthalmology, commercial systems have been developed such as the Imagine Eyes RTX1, which has gained regulatory approval and is increasingly being used in clinical studies.

In parallel, AO scientists are pushing the frontiers of the technology to enable the next generation of systems to enable new research **[7]**. These include compensating for higher orders of aberrations, at faster correction rates, over larger fields of view and a greater range of wavelengths, and building systems that are more robust, compact, cheaper and automated. In astronomy, for example, wide-field AO is being developed using tomographic correction to allow studies of extended objects, and extreme AO systems are being developed to achieve the highest possible contrast and resolution for exoplanet detection. As extremely large ground-based

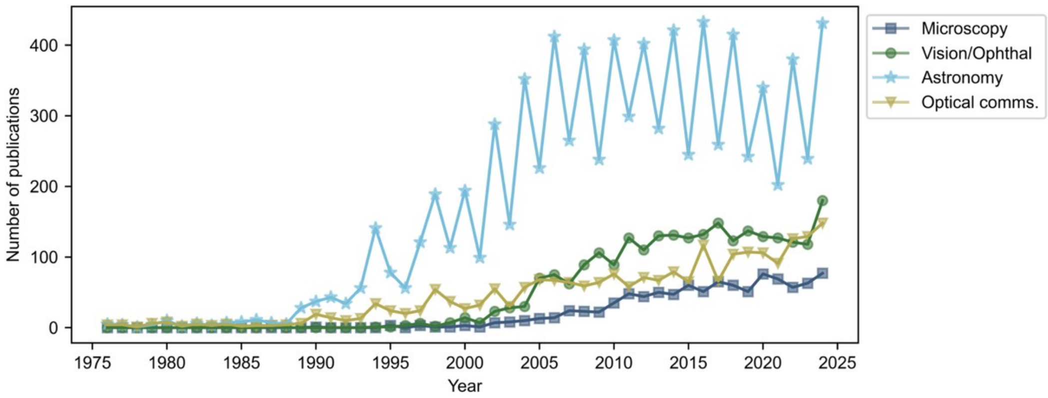

Fig. 1: The number of publications in the four main applications of adaptive optics. Publications were found using Scopus with the following search terms within the title or abstract, and with the additional term "adaptive optics": Microscopy – (microscop*); Vision/ophthalmology – (retina* OR eye* OR ophthalm* OR ocular OR photoreceptor* OR "refractive error"); Astronomy - (astronom* OR telecope* OR observator* OR atmos* OR turbulence) ANDNOT (communication* OR satellite*); Optical communications - (communication* OR satellite*). Keywords were not included in the search due false positives generated from automatically assigned keywords. The term "AO" was not included to avoid false positives from publications involving acousto-optics. The data are limited due to the restriction to the Scopus database and results were not manually validated due to the high number of publications. Search terms were selected based on typical words found in a selection of abstracts, to avoid false positive or misses, additional terms were tested and excluded if they did not change the number of publications by more than ±200. Data are presented up to and including 2024. We believe that the fluctuation in publications in the field of astronomy is likely due to published conference abstracts, perhaps driven by the biennial SPIE conference.

telescopes see first light over the next decade, they will rely on this technology to realise their resolving power. In optical communications with satellites, high-speed and high-order correction are needed to cope with daytime turbulence, low elevation angles, and lower altitude sites. In ophthalmology, AO enables cellular and subcellular resolution imaging and is often integrated with different imaging modalities to enable a range of structural and functional measures of the retina. But challenges persist in imaging individuals with dry eyes, cataracts, difficulties remaining still or fixating well, or retinal pathologies. Stable AO correction is needed to reliably extract information from the retina and to translate systems from research labs into clinical settings. In vision science, AO systems can help understand the normal visual system and how vision is impacted by refractive disorders. Reducing the footprint and cost of AO systems will make it more portable and accessible. In microscopy, samples are usually non-homogenous and so the spatial extent of AO correction is often limited. Biomedical imaging applications also have challenges including sample motions, unavailability of guide stars for wavefront sensing, and photo-bleaching due to prolonged iterative wavefront sensing. Developments in AO are needed to enable correction over a wider field and deeper into tissue, including compensation for scattering.

Whether focused on development of new AO techniques and system design or on use of an AO system for enabling high resolution measurement, high quality training in AO is crucial. Operators using these systems relatively routinely can benefit from a basic understanding of what is going on 'under the hood' of their instrument, allowing them to optimise settings more effectively, understand when there may be a problem that needs fixing or understanding the limits of what their system can do. Operators using these systems are also an important part of the development process, helping to inform system design by providing insights into to the desired capabilities of these systems and their usability. In this paper we discuss an initiative within Europe that began in 2019 – the European AO Summer School – for instruction in AO. We describe the motivations for the school, the design of the programme and how attendance has changed over the last five years.

2 Motivations

The basic principles of AO are common across the various application areas, but each field has its own unique challenges and different ways of using AO. The main motivation for the school was to provide rigorous training in these basic principles so that researchers developing and working with AO systems have a solid grounding in the technology. Reaching across the summer school's programme was a core aim to promote equality, diversity, and inclusion, and to incorporate aspects of career development for a more-rounded experience.

The different application areas have quickly diverged, yet translation of techniques between them over the years has sparked new capabilities **[8]**. The fields of optical communications and astronomy remain closely linked by their need to propagate light through the atmosphere. The fields of microscopy and ophthalmology have remained close, linked by techniques to image through biological tissue and use phase-sensitive techniques. While operating at different spatial and temporal scales, astronomical and ophthalmic systems both use wavefront sensors and laser guide stars and share some common challenges. Similar approaches are adopted within astronomical systems (for static calibration) and microscopes (for wavefront-sensorless correction) to estimate image quality, for example by looking at the point spread function (PSF) or image contrast. One of the main motivations for the European AO Summer School, was to bring these diverse fields together in a single training environment to enable future translation of ideas by exposing students to topics outside of their immediate area of research and providing an opportunity to develop cross-disciplinary links.

Aside from local graduate-level courses and individual workshops, generalised training in adaptive optics has been given by the Centre for Adaptive Optics (CfAO) at the University of California Santa Cruz in the USA since 1999. Indeed, many of the co-authors of this paper attended as graduate students. However, it became clear to us that there was a desperate need for AO training within Europe. Another motivation of the school was to make this training available more locally, and to help strengthen the community of European AO researchers and facilitate future collaborations.

In summary, during the conception and developing of the European AO Summer School, we aimed to do the following while promoting an inclusive training environment:

1. Provide training in the basic principles of AO
2. Connect researchers from all applications of AO
3. Bring together AO scientists and users from across Europe

3 Design of the school

The school was originally planned to be a residential school located in UK in the first year, subsequently moving location within Europe from year-to-year. Due to the Covid19 pandemic, these plans were put on hold and the committee later decided to move forward with a virtual school in 2021. We took this as an opportunity to think differently about how the material was taught and what other online components that we could include to enhance the experience. As we moved to a hybrid format in 2024, we have kept most of these elements while also adding in hands-on sessions allowing students to work in the lab with real systems, as well as in simulation. The various components of the school are summarised below. Across the programme, we have tried to connect material and concepts from different lectures to help students understand how the various principles are linked together.

3.1 Lectures

Our primary aim was to provide introductory training in the principles of AO, and these are delivered by a series of 1-hour lectures from experts in the field. The syllabus includes the main components and the important topics for designing and building an AO system: wavefront sensing, wavefront correction, control, calibration, system design and modelling. We endeavoured to deliver these lectures with a balance of focus on each application area, teaching the generic principles but with examples across the fields. These lectures have been preceded by an introductory lecture giving an outline of how an AO system works, the history of AO and a broad overview of how it is used across fields.

To link across fields, we provide guest lectures by internationally renowned researchers in the fields of astronomy, vision science, retinal imaging, microscopy and free-space optical communications. They provide an overview of how AO is used in their field, what the specific challenges are and what the future might hold. In 2024 and 2025, an additional lecture was added to the programme specifically to cover some examples of new applications of AO. From 2021-2023, during the virtual schools, we also provided pre-recorded short lectures on specific applications including imaging through complex media and machine learning in AO.

We decided from the beginning to include a lecture on equality in the AO community within the scientific programme, to highlight its central importance. A diverse community is best placed to develop diverse ideas. This has been delivered by Prof Céline d'Orgeville based on her work on gender equity in AO **[9]** for which she received a SPIE Diversity Outreach Award in 2021. During this lecture, gender diversity data from the year's cohort are presented and plenty of time is given for discussion. From 2021 – 2023 we also included a lecture on engagement to help students think about ways that they can work with the public and disseminate their research.

Each year we have invited eminent speakers to give a keynote lecture at the school to inspire the next generation of AO scientists, with topics rotated from year-to-year. In 2021 Nobel Laureate Andrea Ghez, professor of Physics & Astronomy and Lauren B. Leichtman & Arthur E. Levine chair in Astrophysics (University of California Los Angeles) gave a talk on her ground-breaking research that led to the discovery of the supermassive blackhole at the centre of our galaxy. In 2022 Na Ji, professor of Neurobiology and Luis Alvarez Memorial Chair in Experimental Physics (University of California Berkeley) gave a talk on her pioneering work in AO for high-resolution fluorescence microscopy. The 2023 keynote lecture was given by Prof Kate Grieve, the scientific director of the Paris Eye Imaging Unit at the Quinze Vingts National Ophthalmology in Paris, on her work developing adaptive optics for retinal imaging applications. In 2024, the first in-person keynote lecture was given by Anne-Marie Lagrange, professor at the Paris Sciences & Lettres University, on her research into extrasolar planets. There was also a guest presentation by Nobel Laureate Alain Aspect, professor and Augustin Fresnel chair at the Institut d'Optique Graduate School (IOGS), on his research into quantum entanglement. In 2025, we hosted Céline d'Orgeville, Program Director of the Australia Telescope National Facility at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), for a keynote lecture on her work on laser guide star adaptive optics.

3.2 Hands-on experience

With the move to an online school in 2021 came challenges in delivery of lab-based training. As this is an important component of the school, we endeavoured to include a live bench demonstration as well as other interactive components, as described in the next two sections. During the virtual school, a demonstration of the AO bench at the IOGS was given, with question-and-answer elements to encourage students to deepen their understanding of what is happening in the system and how it relates to the material given in the lectures. These included sections on the different components of the AO system, examination of the PSF, exploration of the interaction and command matrices and how these are generated, closing the loop and the parameters of the closed loop system, and the interaction between the dynamics of the aberration and performance of the closed loop correction.

Moving in-person in 2024, lab-based sessions were developed based on consultation among the scientific organising committee. The selection of activities was based on a collective idea in answer to the question "what would you like a new PhD student to be able to do in your lab?" As a result, five hands-one sessions were developed, based on the material available at the IOGS:

(1) Alignment and conjugation, covering basic optical alignment techniques using lasers and metrology using an alignment telescope.
(2) Operating a microscope including different illumination strategies, focusing, magnification, resolution, and field measurements.
(3) Interferometry, including characterisation of aberrations using a Zygo interferometer.

(4&5) Operating an AO bench, including two working setups with different correctors – the Imagine Optic Mirao52 and the CILAS bimorph deformable mirror.

In addition to lab-based training, through the five years of the school we have also offered training in AO simulation using AOtools **[10]**, which is an open-source Python Package for analysing data in the pupil plane, images and point spread functions in the focal plane, wavefront sensors, modelling of atmospheric turbulence, physical optical propagation of wavefronts, and conversion between frequently used adaptive optics and astronomical units. A separate demonstration was given of soapy, a Monte-Carlo end-to-end AO simulation package that utilises AOtools **[11]**. From 2022, a retinal image simulation component was added using AOtools to model the effects of aberrations on synthetic images from AOSLO generated using ERICA **[12]**. The simulation workshop, encompassing all three elements, has allowed us to link different concepts in AO, and provide a different medium in which to study them. It also allows students to gain some experience with AO systems at distance, and to continue this after the school has ended.

3.3 Virtual lab tours and industry demonstrations

In moving to an online school in 2021 the committee discussed opportunities to include examples of AO systems that could mitigate to some extent the lack of hands-on experience that would have been provided with an in-person school. At an in-person school it would also have been possible to include visits to local research labs and companies. We decided to replicate this in the online environment in three activities. Firstly, we ran virtual lab tours from research groups across Europe, including work in the fields of astronomy, microscopy and vision science and ophthalmology. Students were given a short presentation of work going on in the lab followed by a demonstration or tour of the bench in use. Secondly, we had a separate set of demonstrations from companies including ALPAO, Imagine Eyes, Dynamic Optics, Phaseform, and Voptica. With each giving an overview of the company and a demonstration of their technologies. Finally, we included a live demonstration from ESO's Adaptive Optics Facility on the 8.2 m VLT at Cerro Paranal in Chile given by Dr Johann Kolb. This telescope was selected for its European connection and its location, which was in a time zone compatible with European attendance during the period of technical activities at the end of a night's observations.

For the virtual schools, tours and demonstrations were followed by sessions in Gather Town (an online spatial meeting platform) where each lab or company had their own 'stand' and students could visit them for further discussion, similar to a poster session or exhibition at an in-person conference. This gave the students exposure to new research going on in Europe, an appreciation of the state of commercialisation of AO, the chance to experience research outside their field, and an opportunity to meet with other researchers and company representatives from across the continent.

Given the success of these sessions, we decided to continue lab tours in the in-person format by providing physical rooms in which students could attend virtual tours presented over zoom, synchronously with online attendees. Industry demonstrations were moved to an in-person format during a poster session, allowing in-person attendees the opportunity to see first-hand the devices these companies are developing, and via a visit to Imagine Eyes in 2024.

3.4 Networking and career development

An important aim of the school is community building and so networking and career development opportunities were an important consideration. Additionally, after months of working from home, online attendance at events can suffer from lack of engagement and a feeling of isolation. While it is not possible to fully replicate the experience of an in-person meeting, we tried to mix in interactive elements to the school to maintain engagement over the week and to give more of a sense of community than simply watching lectures online. Feedback on the virtual schools suggested this worked well and helped participants to feel included. We also considered the different ways that people network and interact, such as preferences for structured vs. unstructured activities or face-to-face vs written communication and tried to provide a variety of opportunities to cater to different needs. Additionally, opportunities for networking came from the virtual lab tours and industry demonstrations, described above.

Networking can be challenging in an online format, however, by 2021 most people in the research community were highly familiar with virtual tools in the absence of physical meetings. To facilitate these interactions online we provided a dedicated "Networking and icebreaker" session (a structured activity) early in the school to give time for the students to meet and get to know a little bit about each other. This included "The wheel", which was spun to randomly select a willing attendee to share an informal photo about them, where they live or work, or what they like to do. Committee members and those giving lectures and tours were included too, so that there was an opportunity to get to know more about the faculty and contributors of the school and to help attendees to ease into a more informal part of the week. This was followed by a sequence of randomly assigned Zoom breakout rooms (an unstructured activity) with up to 6 people (attendees and faculty) and example topics were suggested to start off discussions (to provide some structure, if needed). Further interactions were facilitated by the use of a Gather Town space, which was accessible for the week. Attendance in Gather Town was encouraged by a virtual registration session at the beginning of the school, allowing participants to meet some of the committee, ask questions, and virtually 'bump into' other attendees for a chat (i.e. unstructured interactions). We also provided a Slack workspace for asynchronous discussions and a way to communicate with each other in written rather than verbal form.

When the school moved to a hybrid format, the networking session was replaced by a poster evening, providing a combination of structured and unstructured interaction for in-person attendees. Each student submitted a poster giving some information about the research they are doing or plan to do in the near future. We also held a social event – a cruise on the River Seine – as well as the usual opportunities to meet such as coffee breaks and lunches. The Slack workspace was maintained for asynchronous communication, but this was not well used with in-person attendees preferring to form their own communications groups on WhatsApp and online attendees tending to ask questions via Zoom. While we attempted to include online attendees, networking opportunities for virtual attendees were reduced and it was difficult to form connections between in-person and virtual attendees.

To offer opportunities for career discussions we included dedicated sessions in the virtual schools, with contributions from researchers at different career stages, representing the different application areas and covering both academia and industry. These took the form of open discussion between students and either an individual (in 2021) or a panel (in 2022 and 2023). The hybrid schools naturally offered more opportunities for students to talk with a diverse range of faculty and contributors, and with a formalised opportunity over lunch in 2024.

3.5 Equality, Diversity and Inclusion

It was important to consider diversity in the design of the school, reaching across all activities, to provide a broad range of perspectives on teaching AO and career progression, and to provide a learning environment that is inclusive. This is discussed in d'Orgeville *et al* 2024 **[13]** but in summary we took the following steps: (1) A talk on equality was explicitly integrated into the scientific programme; (2) women, spanning all career stages, were included in the scientific and local organising committees and among the faculty and contributors, particularly in prominent roles; (3) we provided a recommendation on the use of pronouns; (4) the decision to move to a hybrid rather than in-person school in 2024, to open access to those with caring responsibilities; (5) offering scholarships to support attendance from underrepresented groups. We have also collected feedback from participants and as part of that process we have explicitly asked about barriers to attendance. Equality, diversity and inclusion is something that we will continue, to monitor and update our practices based on current recommendations and feedback from participants.

4 Demographics

Participants at the summer school are a microcosm of the current state of the AO community, although potentially biased by factors such as geographic location, awareness of the school (and our advertising strategy), and funding access. There may also be differences in the training needs of researchers using AO systems compared to those designing, building, analysing, and developing AO systems. However, it is still interesting to assess how the demographics of the school is changing over time.

4.1 Research area

Firstly, if we examine how participants from the different application areas of AO have changed over the last five years (see **Fig. 2**) we find that, similar to the analysis in **Fig. 1**, the highest proportion of attendees work in an astronomical application of AO. This has been consistent over the duration of the school, but with some fluctuation in the exact percentage. This has been closely followed by participants from vision or ophthalmology applications. The percentage of participants from an AO microscopy background has always been slightly lower. What is noticeable is the relative number of participants working in free-space optical communications, which has shown a steady increase over the years. As noted above, this may reflect an expansion of research in this

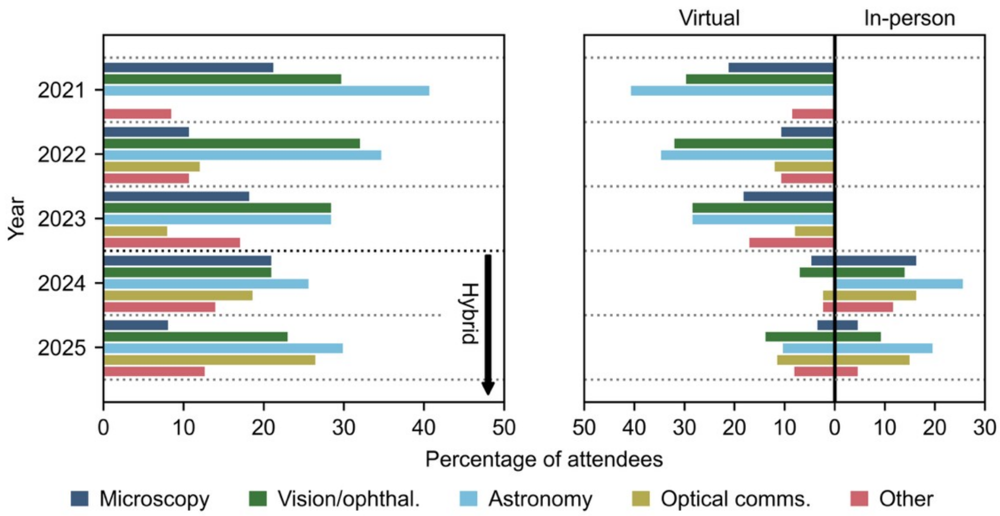

Figure 2: The change in the percentage of students from each application area over time. The left panel shows the data for all participants, and the right panel shows in-person vs. virtual attendance from 2024 onwards. Students were able to select more than one topic area and could also indicate other topics not falling into one of the four main categories.

area, with new students and postdocs entering the field, but we should be mindful that it may also reflect greater and increasing awareness of our school within that community. The move to a hybrid format does not appear to have impacted one research area more than the others. As shown in the right-hand panel of **Fig. 2** (years 2024 and 2025) the percentage of participants attending in-person is generally higher than that of participants attending online and the balance between virtual and in-person attendance is broadly similar across fields. The percentage of participants attending who worked in applications other than the main four has fluctuated over time, but the topics reported have remained similar. These include areas such as beam shaping, imaging through

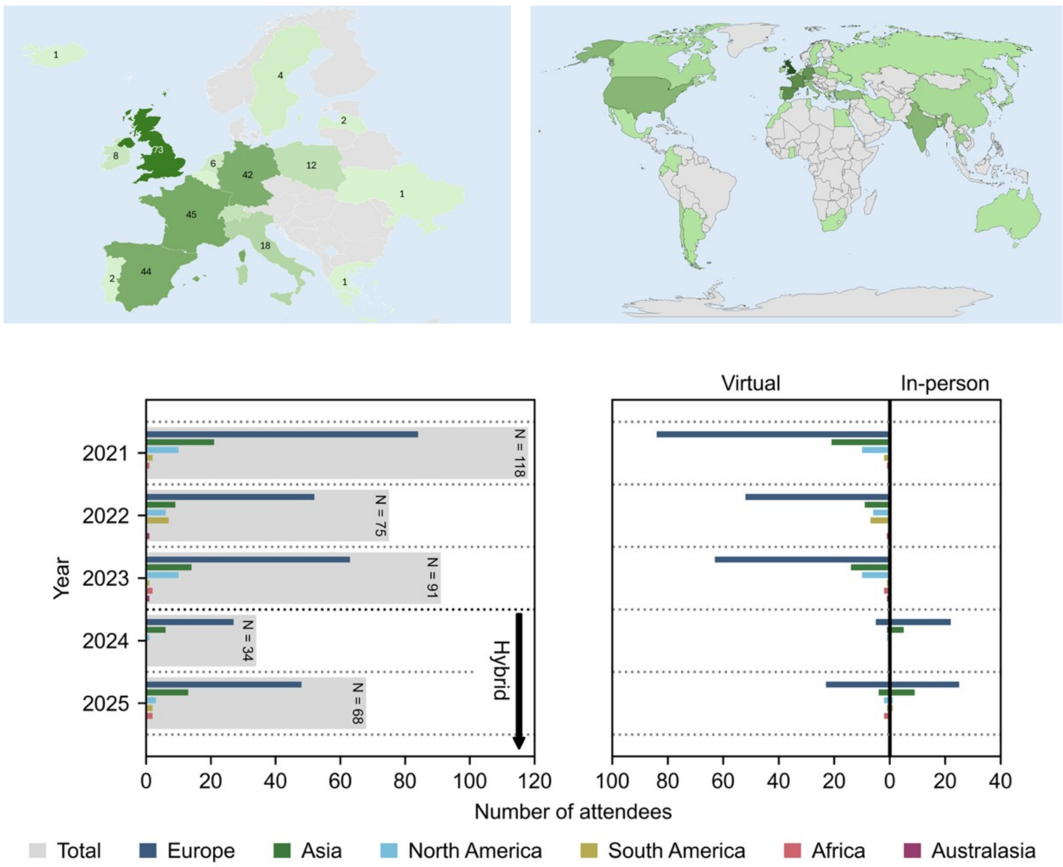

Figure 3: The geographic distribution of participant attendance. The top left panel shows the total number of participants from each country in Europe over the five years of the school. The right panel shows the same data for the whole world. The bottom left panel shows the change in attendance for all participants over time with the total overlaid in grey, and the bottom right panel shows in-person vs. virtual attendance from 2024 onwards. Data are based on the location of the participants' affiliated institution.

complex media, laser fabrication, application-nonspecific technical developments and defence. One of the aims of the school was to

encourage cross-disciplinary links. Overall, representation from the different application areas has been relatively balanced, considering differences in the sizes of those communities.

4.2 Geographic distribution

One of the core aims of the school was to provide a mechanism for strengthening the European AO community and to favour scientific exchanges with the AO community in general. The top left panel of **Fig. 3** shows the total number of participants from each country in Europe who have attended over the last five years. It is evident that attendance is dominated by western Europe, particularly the UK (73), France (45), Spain (44) and Germany (42). This may reflect the geographical distribution of AO research, but it may also indicate differences in access to training funding across Europe. When originally planning a residential school, back in 2019, we did not anticipate global attendance. The move to an online school in 2021 gave us the opportunity to think bigger about the potential reach of the school. Over the five years, we have had attendance from every continent except Antarctica, as shown in the top right and bottom left panels of **Fig. 3**, and while this is dominated by Europe there are many participants attending from Asia. In the hybrid format, attendees are mainly from Europe or Asia, with participants outside these areas tending to join online (see bottom right panel of **Fig. 3**). The virtual schools between 2021 and 2023 saw attendance from North America, but this has reduced both online and in-person in the hybrid format, perhaps due to a preference for more local training. Attendance from outside Europe is driven mainly by India (24), the USA (24), Turkey (19), and Thailand (11). We believe this is a result of a number of factors including: (1) there is a large cohort of AO scientists in the USA who may have taken the opportunity for additional training; and (2) the availability of scholarships prioritising low- and middle-income countries may have boosted attendance from India, Turkey and Thailand, which all have observatories and/or telescope programmes. This is seen explicitly in **Fig. 4**, which shows a small but reasonably consistent attendance from low and middle income countries. In 2025 scholarships were offered explicitly to attendees from these countries and consequently there was a rise in the number of corresponding in-person attendees.

4.3

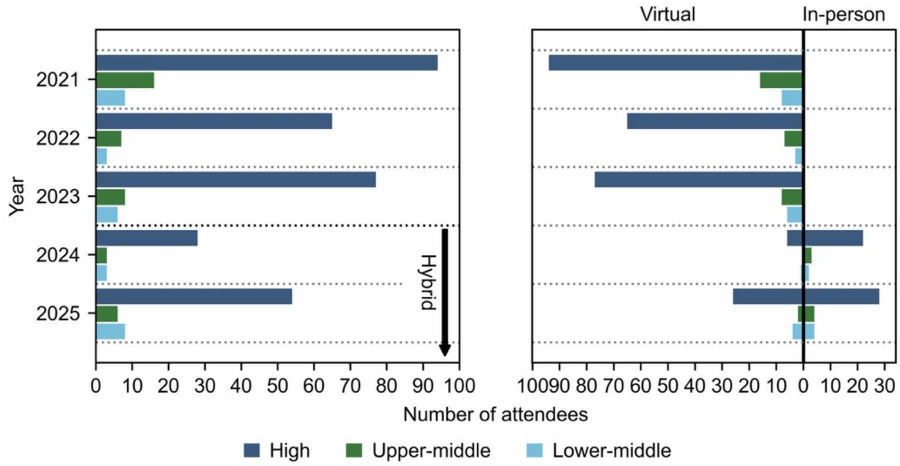

Figure 4: The change in the number of participants according to the income of the country where they were based. The left panel shows the data for all participants, and the right panel shows in-person vs. virtual attendance from 2024 onwards. Data are based on the location of the participants' affiliated institution and the economic status of that country at the time of attendance.

Career stage

The largest percentage of attendees are PhD students, with postdocs and Masters students being the next largest categories, as seen in **Fig. 5**. As the school is primarily aimed at introductory training, and as AO is not a common topic at undergraduate and graduate level, these findings are not surprising. Independent researchers have consistently attended in small numbers, but the number of academics has declined. There has also been consistent representation from Industry, in part being linked to company involvement in the school, either through demonstrations or sponsorship. In person attendance by postdocs reduced in 2025. This could reflect normal variation in the start of research projects, in contrast to the usual annual intake of PhD students on postgraduate courses. It could also indicate difficulties with training funding for postdocs, in contrast to PhD students who often have a training budget. This is something we will keep in mind for future years.

4.4

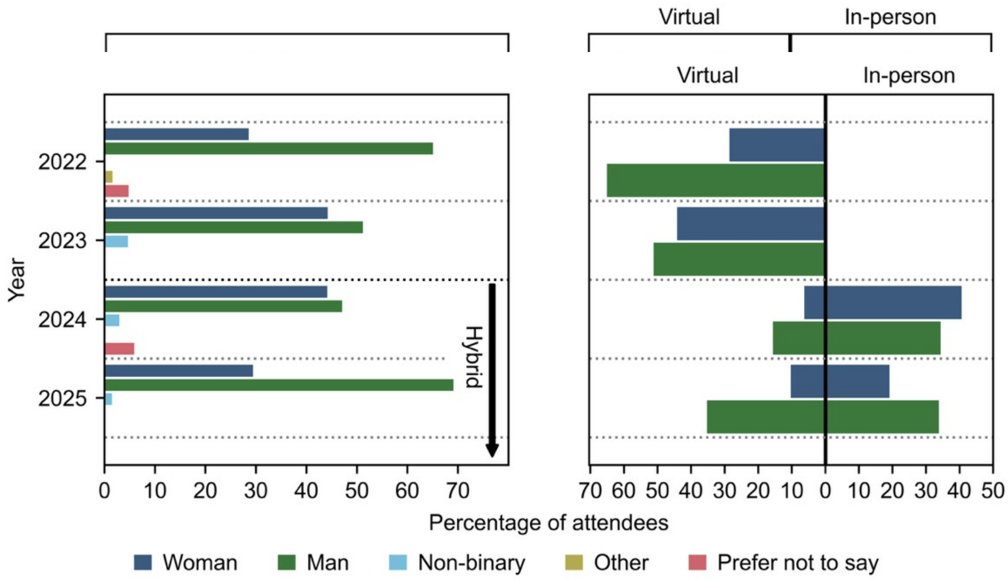

Figure 5: The percentage of attendees from each career stage. The left panel shows the data for all participants, and the right panel shows in-person vs. virtual attendance from 2024 onwards. The "Independent researcher" category includes participants who run their own research projects or programmes as primary investigator, such as researchers holding a fellowship but who are not on an academic contract. The "Academic" category includes lecturers, assistant/associate professors and any other tenured or tenure-track position. The "Technical" category includes roles such as telescope operators and software engineers.

Figure 6: The gender with which participants identified. The left panel shows the data for all participants, and the right panel shows in-person vs. virtual attendance from 2022 onwards. Gender identity data are not included for 2021. In the right-hand panel only the percentage of men and women are reported, to protect anonymity.

Gender identity

We have been monitoring the gender balance of the school, and this has been included in the Equality lecture each year. As shown in **Fig. 6**, by 2024 the school had reached gender parity but in 2025 women were once again outnumbered by men, this time by a factor of more than two. There may be an impact of the scholarships, who were more numerous in 2024 and without eligibility restrictions. Examining the difference between virtual and in-person attendance, we see that gender was more balanced in-person, but it was still far from parity. There have been a consistent but small number of participants identifying as non-binary or a gender other than woman or man, and only a small number of people who prefer not to share their gender identity. We shall continue to monitor this in the future and look for any barriers that may prevent women, or other underrepresented groups, from taking part in the school. Feedback so far has not given strong indications for specific barriers other than a lack of funding.

Data from the 2022 to 2024 schools were included in a publication on gender equity in adaptive optics, which looked at the field as a whole **[11]**. Via an international survey, that study found that over the last decade the proportion of AO scientists who are women has increased, particularly in the younger population (aged 20-29), although it has not reached parity – in 2024 women represented 33% of individual respondents and 29% of staff reported by institutions. The representation of women at the school is thus greater than (in 2022 and 2024) or equal to (in 2025) these values. It is therefore somewhat reassuring that even though we are not consistently reaching parity, we are at least attracting a proportionate representation of women.

5 Summary

Over the last five years, we have provided training in AO to scientists from across and beyond Europe. The continued success of the school and the interest in participation from young AO scientists is reassuring for the future of the community. Positive interactions during these schools bodes well for future collaboration and translation in the different applications of AO, to tackle new challenges and enable new measurements. As we move forward, continuing to monitor the make-up of the school's participant cohorts, adapting and updating the syllabus, and securing funding to widen access to the school, will allow us to continue delivering this service to our community.

Acknowledgements

We would like to thank all those who have contributed to the school over the last five years, including: Jocelyn Cammack, Jean-Marc Conan, Chris Dainty, Oliver Farley and Gordon Love who have previously taught on the course; Alain Aspect, Andrea Ghez, Kate Grieve, Na Ji, and Anne-Marie Lagrange, and who have given keynote lectures; Alexandre Aubry, Carlos González-Gutiérrez, María Viñas Peña, and Patrick Salter who provided recorded mini-lectures; Charlotte Bond, Stefano Bonora, Elisabeth Brunner, Samuel Bucourt, Anne Costille, Chris Dainty, John Girkin, María Viñas Peña, and María Sagrario Millán who provided careers advices to attendees; Johann Kolb for giving live demonstrations of AO correction on the AOF at the VLT; and all of those who have contributed to virtual lab tours and demonstrations over the years – Julius Ameln, Pierre Baudoz, Ali N. Bharmal, Marco Bonaglia, Runa Briguglio, Elisabeth Brunner, Yao Cai, Vincent Chabouleron, Simone Esposito, Florian Ferrera, Alvaro Fernandez Galiana, Marie Glanc, Wolf Harmening, Alexander Jesacher, Léa Kraft, Richard Lane, Veronika Lukyanova, Yifei Ma, Jalo Nousiainen, Brian Patton, Pouya Rajaeipour, Paul Roquette, Santiago Sager, Pierre Senée, Maximilian Sohmen, Lazar Staykov, Danail Stoychev, Brian Vohnsen, Jingyu Wang, Mohan Wang, and Yuyao Xiao.

Finally, we would like to thank our generous sponsors: Institut d'Optique Graduate School, Université Paris-Saclay, Graduate School Engineering and Systems Sciences and Institute for the Sciences of Light at Université Paris-Saclay, Agence Nationale de la Recherche, Laboratoire Charles Fabry, Action Spécifique Haute Résolution Angular (CNRS Earth & Universe), ALPAO, Dynamic Optics, Imagine Optic, Phaseform. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004719. We would like to show our appreciation for all of the hard work done by the Institut d'Optique Graduate School staff, particularly Thierry Avignon and Cédric Lejeune from the Laboratoire d'Enseignement Expérimental (LEnsE) who gave their time to help prepare the experimental hands-on.

References

1. Babcock H W, The possibility of compensating astronomical seeing, PASP, 65(386), 229-236 (1953). DOI: 10.1086/126606
2. Collins G P, Making Stars to See Stars: DOD Adaptive Optics Work is Declassified, *Physics Today* 45(2), 17–21 (1992). DOI: 10.1063/1.2809522
3. Fried D L, Tyler, G A, Strategic Laser Communications Uplink Analysis. (Defense Technical Information Center: Fort Belvoir, VA, USA) 1981.
4. Rousset G, Fontanella J C, Kern P, Gigan P, Rigaut F, Léna P, Boyer C, Jagourel P, Gaffard J P, Merkle F, First diffraction-limited astronomical images with adaptive optics, Astronomy and Astrophysics, 230(1990), L29-L32.
5. Liang J, Willams D R, Miller D T, Supernormal vision and high-resolution retinal imaging through adaptive optics, J. Opt. Soc. Am. A, 14(11), 2884-2892 (1997). DOI:10.1364/JOSAA.14.002884
6. Booth M J, Neil M A A, Juškaitis R, Wilson T, Adaptive aberration correction in a confocal microscope, PNAS, 99(9), 5788-5792 (2002). DOI:10.1073/pnas.082544799
7. Hampson K M, Turcotte R, Miller, D T, Kurokawa K, Males J R, Ji N, Booth M J, Adaptive optics for high-resolution imaging, *Nat Rev Methods Primers,* 1(68), (2021). DOI:10.1038/s43586-021-00066-7
8. E.J. Fernandez (Ed.), Handbook of Adaptive Optics: From Foundations to Applications, 1st ed., CRC Press, 2024. DOI: 10.1201/9781003163671
9. D'Orgeville C, Rigaut F, Maddison S, Masciadri E, Gender equity issues in astronomy: facts, fiction, and what the adaptive optics community can do to close the gap, Proc. SPIE 9148, Adaptive Optics Systems IV, 91481V (2014). DOI: 10.1117/12.2059088
10. Townson M J, Farley O J D, Orban de Xivry G, Osborn J, Reeves A P, AOtools: a Python package for adaptive optics modelling and analysis, Opt. Express, 27 (2019), 31316-31329. DOI:10.1364/OE.27.031316
11. Reeves A, Soapy: an adaptive optics simulation written purely in Python for rapid concept development, Proc. SPIE 9909, Adaptive Optics Systems V, 99097F (2016). DOI:10.1117/12.2232438
12. Young L K, Smithson H E, Emulated retinal image capture (ERICA) to test, train and validate processing of retinal images, *Sci Rep,* 11(2021), 11225. DOI: 10.1038/s41598-021-90389-y
13. D'Orgeville C, Martinez Rey N, Hellemeier J, Masciadri E, Rigaut F, Haynes R, Hibon P, Kewley L, Kulcsár C, Sikora J, Singh R, Young J, Gender equity and diversity in astronomy and adaptive optics: what has changed since 2014 and what more can be done, Proc. SPIE 13097, Adaptive Optics Systems IX, 130971E (2024). DOI: 10.1117/12.3019314