

Institution: University Hertfordshire
Unit of Assessment: 9 Physics
<p>1. Unit context and structure, research and impact strategy</p> <p>Context and Structure</p> <p>The Unit has benefitted from substantial strategic investment over the reporting period in both staff and infrastructure which has allowed it to broaden its research base into new areas, increasing sustainability, while maintaining the vitality of existing areas of excellence. This resulted in a net increase from 33 FTE staff submitted to REF2014 to 42 FTE staff for this submission, an increase of 27%.</p> <p>All staff submitted to the Unit work in the Department of Physics, Astronomy and Mathematics (PAM), within the School of Physics, Engineering and Computer Science (SPECS), established on 1 August 2020. PAM operated as an autonomous School during the REF 2021 reporting period, as did Engineering and Computer Science. The subsequent restructure creates an infrastructure capable of furthering PAM's commitment to interdisciplinary research.</p> <p>PAM is research-intensive with 80% of academic staff having significant responsibility for research (SRR). This is up from 66% in 2014 and was achieved through a process of strategic replacement of teaching-focused staff with those having SRR. It thus reflects a genuine increase which is aligned with PAM's objective to be a research-intensive department.</p> <p>Notable strategic achievements for the Unit within the period are:</p> <ul style="list-style-type: none"> • Refreshed staff profile through recruitment and progression: 15 new appointments, 13 promotions to Associate Professor/Reader and Professor, 19% early career researchers (ECRs). • 89% overall satisfaction rate (top quartile) in the Postgraduate Research Student Experience Survey (PRES) over REF cycle. • Two 3-yearly STFC consolidated grant rounds providing funding of £2.2M and £1.9M. • Year on year increase pre-COVID-19 in research income throughout cycle. • Athena Swan Silver awarded in 2018 and JUNO Champion Status in 2019. • Kaviraj appointed Co-Chair Legacy Survey of Space and Time (LSST) Galaxies Science Collaboration; Thompson is UK voting representative on Board of Directors, Square Kilometer Array (SKA). <p>Research at the University is conducted within Research Centres and Research Groups (see Institutional Environment Statement). Research Centres are led by a Centre director and have considerable autonomy in how they spend research income, including a share of the overheads earned by the Centre; Research Groups are located and managed within a School.</p> <p>Research in PAM is concentrated in two centres, the Centre for Astrophysics Research (CAR), and the Centre for Atmospheric and Climate Physics Research (CACR), and two Research Groups, the Particle Instrumentation and Diagnostics (PID) Research Group and the Research Group in Mathematics and Mathematical Physics (MMP). The latter was set up during this REF cycle and reflects PAM's strategy of broadening its research base. Staff also participate in two interdisciplinary research centres, the Centre for Research in Biodetection Technologies (CRBT), with Engineering, and the Centre of Data Innovation Research (CoDIR), with Computer Science. These are presented more fully later in the statement.</p> <p>The activities of the four PAM-based Centres and Groups and the staff belonging to them are as follows:</p>

CAR: Brinks, Burningham, Coppin (director), Dale, Devereux, Forbrich, Geach, Gledhill, Hardcastle, Harwood, Jones, Kaviraj, Kobayashi, Krause, Lucas, Martin, Napiwotzki, Pinfield, Ryan, Smith, Stevens, Thompson, Wykes. CAR is home to the lead investigators of several large international surveys, operating at wavelengths spanning the optical to the radio. The Centre is involved in the preparations of a new generation of radio facilities and, through participation by its members, has significant stakes in the next generation of optical/IR space-based observatories and ground-based instruments, including those for high-energy astrophysics. Sub-groups within CAR work on exoplanets and stars (Burningham, Jones, Gledhill, Martin, Pinfield), star formation and the Milky Way (Forbrich, Lucas, Napiwotzki, Ryan, Thompson), and extragalactic astrophysics (Brinks, Coppin, Devereux, Geach, Hardcastle, Harwood, Kaviraj, Smith, Stevens, Wykes). CAR's observationally based research is underpinned by theoretical work using numerical simulations spanning size scales from the formation of star clusters through to cosmological simulations of galaxy formation and evolution (Dale, Kobayashi, Krause).

CACP: Chemel, Hesse, Müller, Sokhi (director), Tatarov, Tiwari (Baran, Met Office: external collaborator in CACP on an 0.1 FTE appointment; not REF2021 eligible). CACP leads or participates in national and international research programmes on air quality, atmospheric processes, atmospheric composition and their interactions with climate. The research exploits the use of single particle levitation, ground based, remote sensing, and satellite observations (Hesse, Müller, Tatarov, Sokhi). Staff develop and apply light scattering models to improve climate predictions (Baran, Hesse) and through advanced high-resolution modelling, investigate aerosol-cloud microphysical and radiative properties of aerosols (Baran, Hesse, Müller). Multi-scale high-resolution modelling is core to the group's capabilities to improve the description of boundary layer processes (Chemel, Sokhi), to understand drivers for variabilities in weather, link atmospheric circulation patterns to climate extreme events, and explain heterogeneities in air quality from local to regional scales (Sokhi, Müller, Tiwari).

PID: Greenaway, Hirst, Kaye, Stanley, Stopford (lead). PID staff build optical systems for detecting, sizing, and classifying individual airborne micro-particles in a continuous airstream. As part of their research strand in atmospheric research, they design and build both aircraft-borne and laboratory-based instruments for identifying the morphology of microscopic ice crystals in high-altitude clouds and/or cloud chambers. PID also develops instruments to monitor or alert for hazardous bio-aerosol. These, and other devices for measuring particulate respirable hazards (e.g., asbestos, PM2.5 particulate matter, crystalline silica) are subsequently licensed for commercial use. The team works in a highly multidisciplinary manner to conceptualise (whole team) and then holistically develop the optics (Hirst), mechanics (Hirst, Stopford, Kaye), interface software (Stanley, Greenaway, Stopford), electronics (Hirst, Stanley) and analysis techniques (Stopford, Stanley, Greenaway).

MMP: Carvalho, Łukowski, Mahbubani, Peresse, Regelskis, Steuernagel, Strickland-Constable, Young (lead). The mathematics and mathematical physics group brings together experts on geometric and algebraic approaches to fundamental physics. The group's work on scattering amplitudes in quantum field theories focuses on novel geometric methods, providing a bridge between recent advances in mathematics and experimental high-energy physics by building models for studying real-world scattering processes (Ferro, Łukowski). In supergravity and string theory, the work on compactifications has a focus on generalized geometries (Strickland-Constable). The group uncovers algebraic and geometric structure in integrable quantum models, especially conformal field theories and their massive perturbations (Regelskis, Young).

Strategy

PAM is a research-intensive department, engaged in research at the highest levels and heavily networked internationally (see section 4). The Unit succeeded in achieving the "future strategic aims and goals" articulated in its REF2014 submission, which focused on "ensuring sustainability and strengthening core research activities via targeted investment in new staff appointments and infrastructure, and exploiting opportunities to enhance the many international and national collaborations" and implementing a staffing strategy that "will be sustained by and

benefit from continuing conversion of longer-term externally funded fellows to staff appointments”.

It was recognised in 2014 that the demographic profile and size of some groups making up the Unit made them vulnerable. Research activity, and the resulting income generated, varied substantially across the subject areas in the Unit. The challenge was to redress these imbalances, ensuring the Unit’s long-term sustainability and enhancing its vitality, while staying within the financial envelope set for the department by the University.

The following strategy was delivered:

Broadening the research base of the Unit: Retirement of teaching-focused staff offered a unique opportunity to substantially accelerate the development of the MMP research area. The Unit made strategic appointments, at the lecturer level, of four academic staff, experts on geometric and algebraic approaches to fundamental physics, thus further strengthening the area of mathematical physics. A fifth appointment was made in the area of statistics, again at lecturer level, to contribute to the CoDIR interdisciplinary research centre. These appointments doubled the research base in MMP while rejuvenating its staff profile, laying the foundation for future growth.

Strengthening research with commercial partners: Two members of staff on fixed-term research contracts were transferred to permanent contracts, one in PID and one in CACP. In addition, PAM obtained in-kind support from the University’s Business Development team, allowing it to employ two full time and one part time specialist technical staff in direct support of the laboratory intensive PID group. This enabled PID to continue to be both proactive and responsive to requests from industry.

Fulfilling a commitment to the development of early-career researchers: the Unit successfully participated in bids to two University funded initiatives aimed to promote research that were launched over the reporting period, i.e., the Early Career Research (ECR) and Vice-Chancellor’s Fellowships. Both are 5-year fellowships, with the expectation of the ECR Fellows subsequently being offered a permanent contract. The Unit was highly successful, being awarded two of each. Three of the Fellowships (one ECR- and 2 VC-Fellowships) went to strengthen research in CAR, the remaining ECR Fellowship went to CACP. The Fellows hired were all independent researchers, aspiring leaders in their fields. The three fellows in CAR add expertise to the areas of extrasolar planets and their atmospheres, galactic and extragalactic star formation, and the study of active galaxies, respectively; the fellow in CACP is examining the connections between atmospheric circulation patterns and climate extreme events through the use of multi-scale downscaling approaches to assess sensitivities between weather and regional climate.

Bolstering the Unit’s expertise in numerical simulations and modelling: Numerical simulations are key to interpreting and putting into context observational data gathered by staff from across the Unit. In line with investment in infrastructure, viz. the High-Performance Computing cluster (see below), two new appointments were made in CAR to exploit its capability, doubling the number of staff in CAR developing and running simulation software.

Further diversify income streams: The Unit horizon-scans for both traditional and new funding opportunities. Examples of the latter are the Unit’s involvement in the Newton Fund initiative Development for Africa through Radio Astronomy (DARA), with the key aim of creating sustainable radio astronomy groups across Africa with transferable skills for wider job and wealth creation. Subsequently, and alongside DARA, a similar Newton Fund project, led by members of CAR, was initiated to support the Thai Government to develop the advanced skills the country requires to build a 40-m world-class radio telescope to be incorporated in global radio telescope networks.

Interdisciplinary Research

In 2015 the University adopted six global-challenge focussed Research Themes to facilitate cross-university interdisciplinary research. The Unit is primarily active within the Space theme, whose Theme Champion is Lucas, and worked to establish two interdisciplinary research centres Centre for Research in Biodetection Technologies (CRBT), in May 2017, and Centre of Data Innovation Research (CoDIR) in November 2018.

CoDIR: Geach (director), Blyuss (UOA3) Jones, Kaviraj (plus Department of Computer Science staff: Steuber, Kadir, Schmuker as core staff). This is a new research centre that combines data science and machine learning expertise from astrophysics (Geach, Kaviraj, Jones), statistics (Blyuss), and computer science, particularly biocomputation (Steuber, Kadir, Schmuker). The objective of CoDIR is to pioneer innovative data science techniques, exploiting expertise in statistics, image analysis, machine learning and computational neuroscience to develop a strategy to translate these techniques beyond fundamental research, such as medicine, defence, and agritech. By embedding this translational approach in the centre's research programme, it seeks to deliver economic and societal impact from blue skies research.

CRBT: Stopford, Kaye, Greenaway (plus Department of Engineering staff: Coudron, Dimov, Johnston (director), McCluskey, Tan, Tracey). CRBT combines expertise across areas including particulate matter, aerosols, microfluid flows, and biological sample manipulation. Dedicated specialist groups include applied optical light scattering for airborne particle monitoring (Stopford, Kaye, Greenaway), advanced applied microfluidics for sample processing and biological identification of pathogens (Coudron, Dimov, Tan), and integrated systems combining aerosol collection and microfluidic diagnostics (Johnston, Tracey, McCluskey). CRBT's unique research expertise in aerosol and light scattering physics is also central to the delivery of the EPSRC CDT in Aerosol Science (see below). Ongoing development includes application of existing applied optics and aerosols expertise for research into airborne infection transmission in healthcare settings.

Impact Strategy

The Unit's impact strategy in the period has been to:

Enhance the potential for impact generation in PID: The research performed within the Particle Instrumentation and Diagnostics research group lends itself to applications across areas of public health, biological hazard detection, and atmospheric and climate science. This has made the group a trusted partner to such clients as The Defence Science and Technology Laboratory, Dstl (since 1979), a variety of commercial organisations (viz. Alphasense Ltd., Trolex Ltd, Alert Technology Ltd) and research establishments like the Met Office. Two FTE staff were moved from fixed term onto permanent contracts. The University's Business Development team funds 2.5 FTE of specialist technical support to facilitate collaborations. Two Impact Case Studies (ICS) derive from these activities.

Transfer of techniques developed for astrophysics research in CAR to other domains:

Research in astrophysics is characterised by dealing with big data volumes (Big Science) and complex analysis techniques. Many of these techniques are based on variations of supervised and unsupervised machine learning (AI). The techniques, once developed, often can be applied to areas beyond astrophysics. To actively explore this kind of translational development CoDIR was established, bringing together in an interdisciplinary setting existing expertise in CAR in machine learning and data science with that in Computer Science. Funding from the University's Business Development team for research students was instrumental for exploring the prospect of commercialisation of astrophysics techniques. The application of techniques developed for astrophysics to other domains has already led to a contract with Dstl (via subcontracts with ATLAS Elektronik UK Ltd.), applications in the analysis of medical imaging (in the area of cardiovascular radiography) and a successful bid to STFC under its CLASP Programme to develop and bring to market its ClearSky technology in partnership with Agrimetrix.

Engage in capacity building in Africa and Asia: CAR staff are involved in the preparations of the next-generation radio instrument, the Square Kilometre Array (SKA). The cost of SKA Phase 1 including construction of the two telescopes and the first 10 years of operations (2021-2030) is estimated to be around £1.7 billion. CAR is a main partner in capacity building of aspiring scientists in SKA partner countries in Southern Africa through the provision of training within the Development in Africa with Radio Astronomy (DARA) network, led by University of Leeds. Based on the success of that programme CAR took the lead of a pilot programme of human capital and technology development in Thailand, whose aim, with partner Universities of Manchester, Leeds, and Oxford, is to support the Thai Government to develop the advanced skills the country requires to deliver its flagship national infrastructure project: a 40-m world-class radio telescope that will allow Thailand to access the SKA. In 2016 CAR made a successful £60k bid to the Newton Fund and STFC and in 2017 this pilot project was extended for two more years with the further award of £500k. The combined DARA and Thai projects have resulted in an ICS, and a combined grant income, including £400k for a similar initiative in Colombia, of £1.3M.

Expand and leverage the dissemination of astrophysics research: CAR is engaged in research that attracts world-wide attention, such as the ground-breaking discovery of a rocky, Earth-sized planet, named Promixa b, orbiting the habitable zone of Proxima Centauri, 4.2 light years from Earth, and of four Earth-sized planets orbiting Tau Ceti, at 12 light years distance. Two of them are 'super-Earths' located in the habitable zone of the star. CAR has used its leading role in exoplanet research to engage the public, and particularly school-age children. These and other exoplanet discoveries are reflected in an ICS. The Unit's outreach and public engagement has been supported by £65,000 to acquire one of the UK's largest portable planetariums for school visits and use during Open Evenings at the Unit's Bayfordbury Observatory.

The Unit's impact agenda has throughout the reporting period benefitted from the University's allocation of 5 small grants for research impact totalling £16.1k and support from the Business Development team for activities showing commercial potential. Most recently PAM had a portfolio of 22 projects in the Intellectual Property pipeline across a range of Technology Readiness Levels, 5 of which were at an advanced stage (TRL 7 – 9).

Open Research Environment and Integrity

The Unit has long favoured an open research environment with computer code being shared on GitHub and outputs being made available through repositories such as arXiv (Green Open Access). Staff make their outputs available at a minimum as Green OA and, funding permitting, as Gold OA.

The Unit adheres to the UKRI Common Principles on Data Policy. At an institutional level the University subscribes to the Concordat on Open Research Data. Data obtained fall predominantly in the realm of astrophysics. Raw data obtained at the ground- and space-based astronomical observatories are archived at source by the relevant observatory and, after a suitable proprietary period, become open access as a matter of course. Science-quality data products are made available through data releases and, to ensure long-term curation, deposited in observatory managed data repositories (e.g., ESO, NRAO) or data centres (CDS Strasbourg).

Data related to atmospheric science, collected and analysed through various projects in CACP, are routinely made available after a suitable, typically 2-year, embargo period to facilitate publication of key findings by the project team. This is in line with the requirements of project funders.

The University is a signatory to the Concordat to Support Research Integrity. There is centrally provided mandatory training on research integrity for all researchers including workshops, an annual seminar and the University Doctoral College has its awareness embedded in the mandatory researcher development training for all postgraduate research students (PGRs). Unit staff actively participate in the periodic update workshops and the annual seminar run by the University.

Future Strategy

The Unit has created a sustainable base through building up its constituent parts and increasing its vitality through attracting new staff. The future strategy is:

To further strengthen the area of atmospheric and climate physics research: Following a £1.2M investment PAM intends to bring its advanced Lidar facility into full operation. Planning, construction of the Lidar Laboratory facilities, and installation of equipment commenced during the REF cycle with commissioning now planned for 2021/22; the project suffered delays because of the impact of COVID-19 on both the University and suppliers of bespoke laboratory equipment and parts. This development complements related research taking place in CACP and PID.

The Unit will further extend and support the study of air pollution, such as the ongoing CACP project on pollution control in the Greater Delhi area. It is expected that this and similar research elsewhere in the world will lead to policy input that will inform future decisions made by authorities, improving the health of those living in polluted areas in developing countries, and thus provide significant research impact.

A recent strategic initiative under the auspices of the University-level Space Research Theme has been the formal designation (October 2020) of a new interdisciplinary Centre for Climate Change Research. Director Sokhi brought together the work of CACP researchers on aerosol measurements, aerosol-cloud interactions, prediction, and forecasting atmospheric dynamics with teams elsewhere in the University who work on, for example, climate driven stress in cities, assessment of climate impacts on food security, and development of technological solutions to transition towards a zero-carbon society. The formation of this Centre will strengthen the University's influence in the wider national and international climate change arena (for example, it has already joined the COP26 Universities Network) and facilitate major interdisciplinary research activities over the next REF cycle.

To exploit interdisciplinary research centres and the facilities afforded by a new SPECS building: The decision by the University to establish the new School of Physics, Engineering and Computer Science is to be followed by an exciting development of investment in an £85.5M new building for SPECS on the College Lane campus which will bring together researchers who are geographically dispersed through different departmental locations. This will generate new enhanced equipment resources and provide an environment which promotes the development of interdisciplinary projects.

CoDIR's research topics are relevant to all three Departments in the new school and a key objective is to expand the general area of data science research through targeted recruitment of relevant academic staff across SPECS, and across the University. SRR staff will be appointed in areas including mathematical statistics, statistical computing and data science. Research in these disciplines will lead directly to impact and attract both research and commercial funding. For example, the appointment a medical statistician, has led to new collaborations with external partners including healthcare organizations in medical data analysis.

The Unit's contribution to developing CRBT will be through strengthening PID. This will in the first phase be in the form of the provision of specialist technical support staff. In the longer term the development of the new building will lead to a step change in the quality of the laboratory and technical facilities available to PID. PID's success has historically been based on the efforts of a small number of core academic staff and these numbers will be increased through targeted strategic recruitment, adding vital expertise and skills.

To further extend support for numerical simulations and modelling: In-house expertise in numerical simulations, alongside observational studies ranging from the optical to the radio, gives astrophysics staff a substantial advantage over colleagues elsewhere. This is likely to result in increased external grant income. In CACP, high-performance computing is indispensable for running the sophisticated models that describe boundary layer processes, link

atmospheric circulation patterns to climate extreme events, and reveal variations in air quality from local to global scales. In view of the importance of numerical simulations and modelling, support will be extended for this crucial activity.

To rebalance research funding, research allocations, and availability of PGR studentships across the Department: The restructuring as a result of the formation of the new School has given PAM the opportunity to make the approach to research support more equitable across the department. All staff with SRR, including new hires, will be given appropriate workload and travel allocations to enable them to build up a research profile and to obtain external grant income. Growth in the number of staff with SRR will be accompanied by further increase in postgraduate research (PGR) students by 30% over the next 5 years, adding to the vitality of the Unit. This growth will be achieved through targeted use of QR, overhead, and Unit income.

To build the reputation of the MMP Research Group: it is expected that staff in MMP will benefit from the measures that are in place in PAM supporting new and existing staff (see Section 2, Staff Development) and the above-mentioned rebalancing, to take forward their research, gain further recognition, and as a result increase their grant income.

2. People

Staffing Strategy

The Unit's staffing strategy has been informed by its research strategy which was aimed at maintaining a broad research base in astrophysics, improving the demographic profile across both astrophysics and physics, increasing its sustainability by building up research in mathematics, mathematical physics and data science, and developing the interdisciplinary centres, CRBT and CoDIR. The academic staff profile demonstrates considerable vitality with 19% early career and 58% early- or mid-career staff; 17% are women including a reader and a professor, with just under 50% of staff from outside the UK.

Table 1: Staff submitted to REF2014 and REF2021

	CAR	CACP	PID	MMP	Total staff	Total FTE
REF2014	26	5	2	2	35	33
REF2021	23	6	5	8	42	42

Table 1 lists the number of staff submitted to REF2014 and REF2021, and their Centre or Group affiliation. This submission corresponds to a 27% FTE growth in volume. The proportion of department staff submitted has increased to 80% from 66% in 2014. This is an indication of the staffing and development strategies leading to a genuine strengthening of research across the Unit. Of the 42 staff submitted to REF2021, 37 (or 88%) are on permanent contracts.

The following lists staff members who joined the Unit in the reporting period. It indicates the ability of the Unit to appoint high performing junior staff (typically at lecturer level) in line with the overall growth strategy to ensure both vibrancy and sustainability.

CAR

- Burningham: Marie Skłodowska-Curie Action (MSCA) International Fellowship (Outgoing), held at NASA Ames Research Center, California, USA; currently holder of a Vice Chancellor's Research Fellowship.
- Dale: Excellence Cluster Universe, University Observatory, Ludwig-Maximilians-Universität Munich.

- Devereux: joined as a Daphne-Jackson Fellow after a career in industry; currently Lecturer.
- Forbrich: University of Vienna, Department of Astrophysics and the Harvard-Smithsonian Center for Astrophysics, USA; joined on a University 5-yr Early Career Fellowship with proleptic appointment to Lecturer.
- Harwood: Netherlands Institute for Radio Astronomy, ASTRON; currently holder of a Vice Chancellor's Research Fellowship.
- Krause: Max-Planck-Institut für extraterrestrische Physik, Garching.
- Wykes: Harvard-Smithsonian Center for Astrophysics, USA.

CACP

- Tatarov: joined on an MSCA Fellowship, from the Gwangju Institute of Science and Technology (GIST) in South Korea.
- Tiwari: Centre for Atmospheric Sciences, IIT Delhi; joined on a University 5-yr Early Career Fellowship with proleptic appointment to Lecturer.

CoDIR

- Blyuss: Wolfson Institute of Preventative Medicine, Queen Mary University of London (submitted to UOA3).

MMP

- Ferro: Arnold–Sommerfeld–Center for Theoretical Physics, Ludwig–Maximilians–Universität, Munich (currently on secondment; not REF2021 eligible).
- Łukowski: Mathematical Institute, University of Oxford.
- Mahbubani - Albert Einstein Center for Fundamental Physics, Institute for Theoretical Physics, University of Bern.
- Regelskis: Department of Mathematics, University of York.
- Strickland-Constable - School of Mathematics, University of Edinburgh.

Three staff were funded in part or entirely during the reporting period through external grants (Geach on a Royal Society University Research Fellowship, Devereux on a Daphne-Jackson Fellowship, and Tatarov on an MSCA Fellowship). A further four hold university fellowships, Forbrich and Tiwari on an ECR-Research Fellowship and Burningham and Harwood on a Vice-Chancellor's Research Fellowship.

Staff Development

Great importance and attention are given to the personal development of researchers within PAM. To this end the department maintains a relatively flat management structure with the Head of Department line-managing a group of senior academics who in turn line-manage all remaining staff. Appraisals take place on a yearly basis (usually with an interim review after 6 months) with a standing item to discuss career planning and progression.

This attention to staff aspirations has since 2014 resulted in a string of successes in terms of career progression: 5 staff on fixed-term contracts such as (senior) research fellow or early career Research Fellow, were offered permanent contracts at Lecturer/Senior Lecturer (SL) level. Of those at SL level, 2 became Principal Lecturer and 8 were promoted to Reader/Associate Professor. Lastly 5 Readers were promoted to Professor. Since 2019/20 the has University operated a yearly academic promotion to the titles of Associate Professor, Reader, and Professor which followed on from the introduction of an annual round for promotion to Associate Professor in 2017/18.

All newly recruited staff are provided with a formal induction to the department and are assigned a mentor, someone who is at the same career stage as the new staff member and who can familiarise them with their new work environment and the overall University structure. The new staff member and mentor will have frequent, informal contact. More formal mentoring is

performed by the line-manager who conducts three probation interviews in the new staff member's first year.

New academic staff members who are independent researchers are provided with a substantial research time allocation of typically 55% and are given priority in the allocation of PhD students. The objective is to allow new staff to develop to their full potential and to subsequently take on research leadership roles in their subject area. They are supported in applying for external funding by means of a process of internal moderation and coaching by experienced staff.

In order to further assist, in particular early career staff with their career progression, as well as those not yet having SRR but aspiring to develop their research activity and independence, staff are encouraged to engage with the Doctoral College's Researcher Development Programme which is inspired by and follows the Concordat to Support the Career Development of Researchers (the University was awarded the European Commission's "HR Excellence in Research Award" in 2010 and retained this distinction following its recent 10 year review). PAM actively supports the transfer from (fixed term) research contracts to permanent academic contracts. Over the reporting period, there have been 5 such transfers.

The career progression of mid-career and senior staff also involves continuing professional development (CPD) to prepare and assist staff taking on management roles, such as line-management, appraisal, serving on or chairing a recruitment panel, etc. CPD is coordinated by the University's HR department. Staff interacting with industry, i.e., those engaged in research with the potential for research impact, are provided maximum flexibility to deliver an agile response to requests for their expertise from outside academia. This in general translates to reduced teaching allocations and teaching in module teams. Seven staff, primarily, but not exclusively in PID, are currently engaging with commercial partners and industry.

The School actively promotes career development and supports staff bids for grants such as Royal Society/Leverhulme Senior Research Fellowship that allow the individual to concentrate exclusively on research for the duration of the grant. Likewise, if financial support is provided by a host institution for research visits, a period of extended sabbatical leave is usually granted. Typical recent examples just before the impact of COVID-19 when 5 staff were on leave for part of one semester (Steuernagel, Kobayashi, Regelskis) or a full academic year (Coppin, Ferro). This allowed Steuernagel to accept invitations prompted by his recent research on Wigner flows which has led to new collaborations (A. Klimov, Guadalajara, Mexico; R.-K. Lee, National Center of Theoretical Sciences, Taiwan). Kobayashi visited her collaborators in Melbourne and was invited to become a partner investigator of ASTRO3D, a £22.4M Australian Research Council Centre of Excellence in All-Sky Astrophysics in 3 Dimensions (ASTRO 3D), which runs until 2025.

The Unit recognises the importance of staff disseminating their work, e.g., at workshops and seminars. CAR, for example, provides a travel budget of £2000 per staff member each year including PDRAs (and £1500 p.a. for PGR students). In addition, there is an active Visiting Researcher programme covered largely through the STFC consolidated grant, to invite collaborators for short (several days to weeks) stays. Staff who are not part of a Research Centre are supported directly through the departmental budget.

Research Students

The University participates biennially in the Postgraduate Research Experience Survey (PRES). PRES 2019 ranked the University overall experience 21st out of 103, 4th of 103 for research culture and 15th of 103 for supervision (62% response rate). Reporting the average scores across the three surveys held during the REF cycle to take account of the small number of respondents, satisfaction levels are at 88% in the category 'Supervision', 93% for 'Resources', and 89% in 'Overall experience' which places the Unit in the top quartile of the sector.

Table 2: Number of Doctoral awards

	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
Number students	5	12	7	6	3	4	9

Table 2 lists the annual number of Doctoral awards over the reporting period, being a total of 46. In addition, there were 3 PGR students, who in their writing-up phase had moved overseas and were therefore classified as distance learners in the University's HESA return, thus making a total of 49 of which 27% are women. At the census date, 38 PGR students were enrolled on a PhD. A further 11 are working on a 1-yr MSc by Research. This projects to 9 or 10 doctoral awards per annum, showing an increasing trend which benefits from participation in the EPSRC Centre for Doctoral Training (CDT) in Aerosol Science (see Section 4).

For doctoral students, 82% are supported through a studentship, the remainder being self-funded. For studentships, 19 are provided through the STFC DTG, EPSRC CDT, and individual grants held by staff, and 12 through QR funding.

Table 3: Destination of PGR students

Destination	Number
postdoctoral career	15
academic career/R&D	9
data analyst/scientist	10
commercial/finance	4
teaching	4
other	7

Table 3 provides the next stage destination for PGR students. The majority continue their career in academia, usually with a postdoctoral appointment, both nationally (recent examples include Oxford and Durham) and internationally (for example, ASTRON, The Netherlands; ANU, Canberra and UWA, Perth; Steward Observatory, Arizona and Johns Hopkins Applied Physics Laboratory, Baltimore; Astronomical Observatory, and Rome).

PGR students are assigned a supervision team, consisting of a principal and at least one further supervisor. This arrangement not only benefits the student but staff who are new to supervising at doctoral level can gain experience (all staff involved in PGR supervision must complete training arranged by the Doctoral College). In addition to the expectation of regular interaction of the student with supervisors, there is the requirement of a minimum of three progress meetings of the full team per year, each followed by a brief report, and additionally an annual monitoring report. Students must pass two formal assessments in order to progress to the final phase of their PhD, one after 8 and another after 18 months of enrolment (for full-time) where the student's progress is judged by an internal and an external assessor, i.e., someone not involved in the research project.

Although the supervision team covers the pastoral care of their students, they also have recourse to the departmental Postgraduate Tutor. Moreover, there are PGR student representatives both on the department management group and the Equality Committee. The Doctoral College has a Student Forum which meets several times per year and is chaired by one of the Associate Deans (Research).

PGRs are fully integrated in the research environment of the department and its vibrant research culture (seminars, lunch talks, journal clubs, subject specific gatherings). PGRs are in charge of convoking journal clubs and weekly or fortnightly subject specific meetings. They are attached to one of the research centres or groups and share offices within the same buildings as staff. They have identical access to relevant resources as staff and are provided with high specification IT equipment and a travel budget of £1500 a year.

PGRs are offered a wide range of opportunities to develop and expand their transferable skills. These are the Researcher Development Programme, the popular postgraduate training programme “GRADnet” offered through the Unit’s participation in the South East Physics Network (SEPnet), and PAM’s internally run Post-graduate Training programme. PGRs agree with their supervision team those courses and activities that would be of most benefit (a number are mandatory, such as training related to Equality and Diversity, Unconscious Bias, and Research Integrity and Plagiarism). Successful completion of the agreed personal development programme must be reported in the 8-month and 18-month progression reports.

Equality and Diversity

PAM’s Equality Committee works to remove barriers for LGBT+, BAME and women staff and create an equal workspace beneficial to all. No distinction is made between fixed-term staff or those on permanent contracts. Similarly, full-time or part-time staff are treated equally. Equality/Diversity training is mandatory for all staff, as is training to recognise unconscious bias with refresher sessions every three years. Care is taken to ensure hiring and recruitment panels have a balanced composition, as do interview panels for PGR students.

PAM is proud to have been awarded Athena Swan Silver in April 2018 (following its Bronze status since April 2015) and, in July 2019, JUNO Champion status (following on Practitioner level since January 2015). The award letter commended the department for having Equality & Diversity “well embedded in the organisational structure”. The Equality Committee ensures the Athena Swan and JUNO action plans are being implemented.

A family friendly policy supports requests for parental leave and bespoke arrangements for working from home and flexible working to support staff with childcare or caring responsibilities. Staff with SRR returning after maternity leave are offered a phased return with an initially larger fraction of time allocated for research.

Table 4 provides the gender balance for postdoctoral researchers, PGRs, and academic staff. It shows that an increasing number of both early career staff and research students are women, creating a healthy pipeline for future appointments to academic posts. The Unit supports them to further their career ambitions by, for example, participating in the informal Women in PAM network. Kobayashi promoted gender balance at international level, serving from 2012 – 2018 on the Executive Committee of IAU Working Group: Women in Astronomy.

Table 4: Gender balance

	Number	Number of women	Percentage women
Post-doctoral researchers	12	6	50
Postgraduate research students	48	15	31
Unit academic staff	42	7	17

The international composition of the Unit is worthy of note. Just under 50% of staff, 66% of post-doctoral researchers and 38% of PGRs are of non-British origin, creating a vibrant, multicultural, diverse environment.

3. Income, infrastructure and facilities

Income

The largest proportion of research in the Unit is of a ‘blue skies’ nature. 70% of external research income comes from the UKRI research councils (see left-hand panel of pie-chart below). The remaining 30% comprises diverse sources: 11% EU, 6% Industry, 4% Charities, 6% other Government funds, 3% Other. Research Income increased year on year throughout the cycle until COVID-19 affected 2019-20, reflecting the Unit’s successful progression of mid-career staff into research leadership roles.

Table 5a: Research income composition (£Million)

External Income	Central Facilities (STFC)	In-kind Income*	Total
12.9	4.2	9.1	26.2

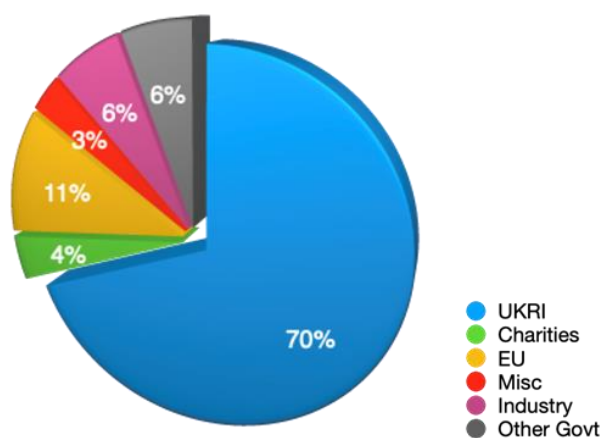
* Calculation of in-kind income associated with competitively awarded public surveys and/or Principal Investigator time not captured by UKRI data.

Table 5b: Annual Research Income over Cycle (£Million)

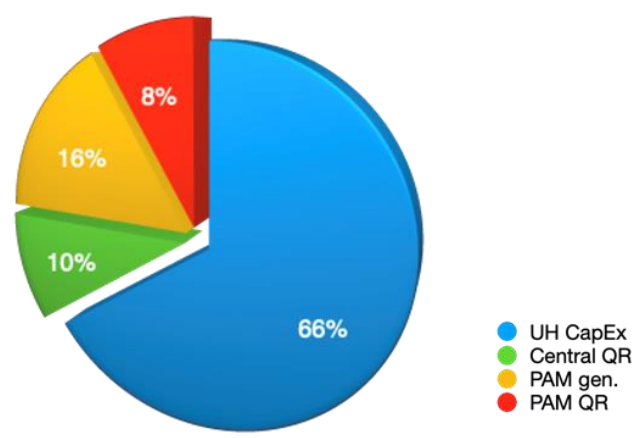
2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	TOTAL
1.5	1.6	1.9	2.0	2.0	2.2	1.7	12.9

Despite serious pressure on STFC resources the Centre for Astrophysics Research was awarded £2.2M and £1.9M in the two 3-yearly consolidated grant rounds that fall in the reporting period. Kobayashi led a collaborative STFC grant valued at £330k (BRIDGCE: The Rise of Chemical Elements). Sokhi was awarded £730k for his Newton Fund project PROMOTE (Process analysis, observations and modelling - Integrated solutions for cleaner air for Delhi). Other large awards were Newton Fund grants totalling £900k for capacity building in Southern Africa and Thailand (Thompson, Forbrich), and a further £400k for a similar initiative in Colombia (Thompson, Geach).

External funding



Infrastructure funding



Our total facilities in-kind income reported by Research England for the period is £4.2M. This incorporates the UOA's regular use of ground-based facilities operated by the European Southern Observatory (ESO), including ALMA, as well as providing access to STFC's DiRAC High Performance Computing (HPC) infrastructure.

Table 6 shows examples of additional in-kind income estimated at £9.1M, which results from principal investigator time allocations awarded competitively on non-UK facilities, illustrating the highly competitive nature of bids from individual CAR staff to the world's top facilities.

Table 6: Examples of the larger in-kind awards

Time	Facility	Estimated value (£k)
544 hours	VLA, VLBA	992
803 hours	SMA	2,058
3152 hours	JCMT/EAO	1,873
317.3 ksec	Chandra	1,951
3000 ksec	INTEGRAL	500
28 nights	GTC, LBT, Magellan, IRTF	621

Infrastructure and Facilities

Moving forward from REF2014 PAM continued its targeted investment in infrastructure in the reporting period with expenditure of £3.6M. The most visible evidence of this has been the setting up of a laser laboratory capable of state-of-the-art Lidar-based research in atmospheric physics led by Müller who joined PAM in 2013 from the Gwangju Institute of Science and Technology (GIST) in South Korea. Investment to date is £1.2M, shared between University and departmental funding. Although the Lidar laboratory has been inaugurated, it has only recently moved from the construction to commissioning phase. In parallel to developing the Lidar research facility, the existing laser laboratory was comprehensively refurbished.

The other critical area of investment is the University's High-Performance Computer (HPC), a Linux cluster worth currently ~£3.3M of which ~£1.0M has come from University funds and £340k from Departmental funds and research grants in the reporting period. Originally pioneered by PAM in 2010, this became a University facility in 2016 with a £1M investment in a hardware upgrade that allowed the HPC to grow to its current capability (5300 CPU cores, 21 TB RAM, 63000 GPU cores and 2.3 PB storage). Unit staff continue to be the largest users of the system, which supports the growing activity in numerical simulations.

Table 7: Examples of the larger investments made

Facility	Estimated value (£k)
Lidar laboratory	1200
HPC facility	1340
JCMT/EAO subscription	150
Drosonde receiver for FAAM Aircraft	193
PAM Public Engagement; portable planetarium	65
Misc. Laboratory upgrades	110

Table 7 lists a selection of the larger investments made over the reporting period. The right-hand panel in the pie-chart above shows the internal source of funding, the bulk of which is through competitive bids to the university's capital expenditure (CapEx) programme (66%), the remainder being provided by QR and departmental disposable income.

The Unit receives QR income which is proportional to its contribution to the success of the University's REF2014 submission (after modest top-slicing by the University). QR funds are strategically used in line with University approved research delivery plans, among other things, to fund staff on fixed term contracts, e.g., in support of the Lidar laser facility. Importantly, QR funds are also used to provide PhD studentships, complementing those supported by external funding.

4. Collaboration and contribution to the research base, economy and society

Research Collaborations and User Partnerships

The bulk of research carried out in the Unit involves national and international collaborations. Those with particularly wide scope and/or substantial leadership from Unit staff are listed below.

CAR large collaborations include:

- Square Kilometer Array: The SKA is the world's largest radio astronomy collaboration, with 15 core participating countries and 8 African partner countries. CAR members of science and technical working groups are Thompson (founding Chair of the "Our Galaxy" working group), Brinks, Forbrich, and Hardcastle.
- The Legacy Survey of Space and Time (LSST) on the Rubin Observatory is a ten-year, deep-wide optical survey, which will reach depths of 28 mag (in the r-band) over 20,000 sq. degree. The project involves more than 1000 scientists across 29 countries. Kaviraj is co-Chair of the LSST Galaxies Science Collaboration. Burningham is co-Chair of the Solar Neighbourhood Working Group within the Stars, Milky Way and Local Volume Science Collaboration. Lucas serves as the Milky Way and Local Volume Point of Contact for the UK consortium within LSST (LSST:UK). Kaviraj is co-PI of an STFC-funded PDRA grant, within the LSST:UK Phase B programme, which is developing pipeline infrastructure for low-surface-brightness science.
- VVV/VVVX: the VISTA Variables in the Via Lactea project and its extension (VVVX) is an international collaboration involving 13 countries and over 100 collaborators. VVV and VVVX have been awarded 400 nights on the ESO VISTA telescope from 2010 to 2021. Lucas is co-leader of the project.
- MeerKAT is the South African SKA precursor. The Galactic Plane Survey (GPS) is an international legacy survey of the Galactic Plane at 1.4 GHz, carrying out the deepest and highest resolution survey yet carried out. The MeerKAT GPS consortium has 50 members from the UK, South Africa, Europe, and the US. CAR members are Thompson (PI & survey coordinator) and Forbrich. The MIGHTEE survey is using MeerKAT to obtain ultra-deep images of the southern extragalactic radio sky (CAR members are Hardcastle, Harwood, Smith). MHONGOOSE is a MeerKAT large survey to map atomic hydrogen in nearby galaxies; Brinks is co-I.
- LOFAR Surveys Key Science project: an international project with 300 members from 80 institutes in 15 countries, carrying out wide and deep low-frequency sky surveys using the LOFAR telescope. CAR partners are Hardcastle (core team member and lead developer of the imaging pipeline) and Smith (core team member and lead of the LOFAR-WEAVE working group).
- LOFAR-UK: the UK national contribution to LOFAR, funded by STFC, running the UK LOFAR station and UK computing infrastructure hosted at the University, with 22 UK universities as members. Hardcastle is deputy PI.
- UKIDSS (Lucas, Pinfield): the United Kingdom Infrared Deep Sky Survey was a UK-led international project involving several dozen researchers in ten countries. It was awarded

c.1000 nights on the United Kingdom Infrared Telescope from 2005--2013 and the final data release (DR10) was completed in January 2015 with the addition of Galactic Plane Survey (GPS) data, one of the five components of UKIDSS. Lucas is head of the GPS.

- WEAVE consortium: an international consortium with hundreds of members worldwide, building the WEAVE spectroscopic facility for delivery to the William Herschel Telescope (WHT) and then spending 70% of all WHT time for five years conducting surveys with it. WEAVE was funded by an international consortium including those that sponsor the Isaac Newton Group of Telescopes (STFC, NWO, IAC) as well as many more. Smith is a WEAVE builder; Gledhill and Hardcastle are consortium members.
- WEAVE-LOFAR: an international consortium containing around 65 members from countries throughout Europe. It will spend five years obtaining more than a million spectra of sources identified in the LOFAR Surveys KSP. Funding for WEAVE-LOFAR has come from STFC, as well as contributions from Leiden University and Edinburgh University. Smith is lead investigator, Hardcastle is a survey builder.
- SASSy: the SCUBA-2 Ambitious Sky Survey was a large programme on the JCMT to carry out a wide and shallow survey of the Outer Galaxy. The international survey consortium has 48 members. Unit participation is Thompson (PI), Chrysostomou and Forbrich.
- SPACE: Submillimetre Polarisation and AstroChemistry in Earliest star formation is a polarimetry and molecular mapping follow-up to the successful SCOPE continuum survey. SPACE is a JCMT Large Project led by China and with over 100 members from the East Asian Observatory partners, the UK and Canada. Thompson is UK coordinator for the survey.
- S2LXS: the SCUBA-2 Large eXtragalactic Survey, a large programme on the JCMT run by an international collaboration of 100 members (UK, Japan and other EAO member states). Geach is co-lead, Coppin and Smith are co-Is.
- S2CLS: the SCUBA-2 Cosmology Legacy Survey, a former large programme on the JCMT run by an international collaboration (UK, Canada, Netherlands). Geach was programme manager.
- LITTLE THINGS: is an international Large Programme on the NRAO Very Large Array to understand the star formation properties of dwarf galaxies. Brinks leads the radio continuum work package and is co-lead of the overall project.
- BRIDGCE: the STFC-funded UK consortium on nuclear astrophysics (BRIDGE the Disciplines related to the Galactic Chemical Evolution) including ~60 members scattered across 16 institutes, started in 2014. Kobayashi is the PI, and Ryan is a co-I.
- AtLAST: The Atacama Large Aperture Submillimetre Telescope: a collaboration performing a H2020-funded (Research and Innovation programme) development study for a new large aperture submm telescope in the Atacama. AtLAST is an international project with leadership from the UK and Europe and involvement from Japan. Geach is co-lead of the science working group, Coppin is a co-I.
- ChETEC: the EU COST Action on nuclear astrophysics (Chemical Elements as Tracers of the Evolution of the Cosmos), 0.6M EUR funded in 2017-2021. Kobayashi is a Management Committee member.
- SCOPE: SCUBA-2 Continuum Observations of Pre-protostellar Evolution is a large survey programme on the JCMT, involving a consortium of over 160 members from the East Asian Observatory partners (China, Japan, Taiwan, and South Korea), the UK and Canada. Thompson is UK coordinator for the survey.

CACP large collaborations include:

- NCAS: the National Centre for Atmospheric Science is a world leading research centre, funded by the Natural Environment Research Council, with over 200 members of staff, embedded at 12 universities and research institutes across the UK. Chemel is core member of staff.
- NERC/MOES project: the Air Pollution and Human Health project, PROMOTE funded by NERC and MOES (India). It focuses on process analysis of air quality in and around

Delhi and consists of 5 UK and 5 Indian organisations with four other international partners (USEPA, WMO, NOAA, PNNL). Coordinated by Sokhi. Other staff involved: Tiwari.

- H2020 project, EMERGE: this focuses on the impact of shipping emissions on the environment and human health. It consists of 18 International partners. Sokhi is lead for WP5 Modelling of Air Pollution from Shipping Emissions. Other staff involved: Tiwari
- PREFIA – Air Quality and Meteorological Prediction and Forecasting Improvement for Africa (PREFIA) is an initiative of the World Meteorological Organisation’s Global Atmospheric Watch Programme (WMO/GAW). It aims to improve air pollution capabilities at local to regional scales for African continent and urban areas. It comprises over 60 African and other international scientists. Coordinated by Sokhi.
- WMO/GAW Programme is undertaking a coordinated study of the impact of COVID-19 lockdown measures on air quality across cities globally. It consists of nearly 100 scientists contributing to the research. This study is being led by Sokhi.
- International Conference on Air Quality – Science and Application is a community collaborative event which started in 1996 at the University and is held every two years. It has become the key international research conference in the field of Air Quality. The committee consists of nearly 30 international scientists. This conference has been chaired by Sokhi since its start in 1996.

Contributions to Economy and Society

The Unit research is disseminated to the public through a wide range of outreach and public engagement channels and through regular media exposure. News outlets featuring the Unit include the BBC (Brinks, Geach, Hardcastle, Jones), CNN (Hardcastle), the Guardian (Geach, Jones), the Mirror and Express (Jones), the Daily Mail (Jones, Sokhi) the Times (Geach) and New Scientist (Jones, Kobayashi). Unit staff regularly contribute to The Conversation (Brinks, Geach, Jones, Krause). Geach has authored two popular books ('Five Photons' and 'Galaxy: Mapping the Cosmos') in the reporting period. A wide range of staff give public talks and lectures to local and national audiences.

Much of the Unit’s public engagement programme is centred around activity at the University’s Bayfordbury Observatory. One of its principal channels is via its public open evenings, which annually welcome over 2000 guests at monthly events between October and March. Unit staff draw on their research to provide talks, planetarium shows and interactive demonstrations. Bayfordbury also hosts around 60 visits per year from a variety of private groups and organisations. These groups bring a total of ~1500 people to the observatory, with ~70% being under the age of 18. Most adult visitors have little to no background in physics or astronomy. Since 2017, Bayfordbury has also served as home base for the UK’s largest mobile planetarium. Equipped with a cutting-edge sound diffusion system and full dome projection, the Cosmodrome has welcomed more than 7000 festival goers since 2018, many of whom have not previously engaged with astronomy research (Burningham). In addition to music and arts festivals, the Cosmodrome is also taken to more traditional regional and national science festivals.

PAM’s Outreach and Public Engagement (OPE) officer leads its work with schools, supported by SEPnet and the Ogden Trust, and delivers its strategy of raising the science capital of young people from hard-to-reach communities. Building on a successful history of working with schools across London, the South East and Central England, the strategy is focused on building lasting relationships with students and schools in the most deprived and underserved communities in the region. In parallel to this, the Unit runs a small number of Space and Physics events at secondary schools throughout the year and hosts the Ogden Trust’s School Physicist of The Year awards for the Eastern Region. A team from the Unit, led by the OPE officer with the active participation of PGR students, also contributes to the Big Bang Fair East of England event, hosted at the University, and runs the mobile planetarium that visits schools across the region.

Unit research contributes to the local and national economy. Within the reporting period a ‘Framework’ agreement, covering both the PID group and the Department of Engineering’s

MEMS group under the title 'Centre for Hazard Detection and Protection Research', was signed between the University and Dstl (2014-2018). The agreement streamlined the awarding of targeted contract research programmes at the University funded by Dstl and was a result of the long (at least two decades) and very successful collaboration that PID had enjoyed with Dstl in the development of bioaerosol detection technologies (Kaye, Stopford). The PID group's long-standing collaboration with Alphasense Ltd. has included job creation (~10-12 new posts dedicated to the production of Optical Particle Counters (OPCs) developed by PID). As a result of the successful collaboration, Alphasense has opened a new 400m² building adjacent to their present site for expansion of the OPC production facility.

Following a successful Dstl-supported scoping project with marine defence contractor ATLAS-Elektronik UK Ltd (AEUK), whose focus was on applying a machine learning algorithm to the automatic detection of submarine hazards in high resolution sonar imaging, CAR was awarded a 3-year STFC Innovation Fellowship in 2018, undertaking a project called 'ASTROSENSE: applying astrophysics algorithms to remote sensing data' (Geach). In this project staff are developing and applying object detection and classification algorithms for astrophysics data (typically imaging, but also data cubes) to other areas. The goal is to develop a versatile, robust algorithm that can be deployed in a variety of practical areas, with a view to performing real-time image classification and analysis on input data, both from astrophysics and industrial sectors.

CoDIR has been involved in the development of a novel deep learning algorithm for Earth Observation called 'ClearSky'. This algorithm can predict the full spectrum visible-infrared reflectance response of the ground using Synthetic Aperture Radar (SAR), providing monitoring of the Earth's surface uninterrupted by cloud. The work has been funded largely through external grant income via STFC (~£285k) and has resulted in UK and international patent applications through the University (UK patent published in February 2021). CoDIR is collaborating with Rothamsted Research-based Agrimetrics Ltd. to deliver ClearSky data products to the agricultural/agronomy industry (Geach). The 12-month project 'ClearSky: cloud-free monitoring of UK agriculture' is funded by the STFC's Challenge Led Applied Systems Programme (CLASP). The deliverables of this project are: (1) weekly monitoring data of every field in the UK (e.g., assessing vegetation density) to be marketed to the agritech sector (e.g., precision farming, large food producers), and (2) a free-to-use mobile and web application providing individual farmers across the UK with weekly monitoring and statistics related to the growth and health of crops and pasture. This information can be used to make on-the-ground decisions improving the efficiency of land use (e.g., optimizing irrigation, fertilization) and improve food security (e.g., identifying environmental threats such as flooding and drought).

CACP influences science agendas through national and international collaboration, often multidisciplinary, to understand how multiscale transport and dynamics of air pollution along with atmospheric composition affect climate (Müller, Tatarov, Tiwari and Sokhi) and human health (Sokhi). CACP is involved in the development and testing of new modelling approaches for characterising composition and morphology of aerosols (Baran, Hesse), downscaling for regional climate, and air quality predictions (Chemel, Sokhi, Tiwari); innovative remote sensing retrieval algorithms are intrinsic strands of CACP's research. CACP staff also engage with policy making bodies such as DEFRA, WHO and WMO (Sokhi). This research will derive significant benefits in the future from emerging developments of the Unit's Lidar system for chemical characterisation of air pollutants and Raman and fluorescence microscopic spectroscopy.

Contributions to Sustainability of Discipline

Unit staff contribute through a variety of ways:

Journal editorships: Staff served in the following editorial roles. Brinks, Section Editor for Physics & Astronomy, SpringerPlus (2012-2016); Editor in Chief, Astrophysics & Space Science (2014-); Editor in Chief (Section Physics and Applied Physics), 4open (EDP Sciences, 2017-). Chemel, Member of the Editorial Board of the journal Frontiers in Atmospheric Science (2013-); Member of the Editorial Board of the journal Atmosphere (2017-). Napiwotzki, Associate Editor,

Astronomy & Astrophysics (2011-2014). Sokhi, Journal of Urban Climate, Editorial Board Member.

Participation on grants committees: Unit staff take their responsibility to the broader community seriously and routinely take on grant and proposal review at a range of levels. Some of the more significant activities follow. Brinks served in 2014 as Member on an NSF review panel and in the reporting period served three years on one of the ALMA review panels. He is a Member of the IRAM TAC. He also served on the STFC Ernest Rutherford panel (2018-2020). Burningham was Panel Member 2016-2018 for the NASA K2 Guest Observer Review and served on the NSF (USA) Planetary Astronomy grant panel (2015). Chemel is a member of the NERC Peer Review College. Coppin served on one of the ALMA review panels and on the LMT TAC. Forbrich is member of the e-MERLIN Time Allocation Group (2019-present) and EVN Programme Committee (2020-present) and served on the ALMA (2018-2020) and NRAO (2018-2019) Science Review Panels. Geach served on ESO OPC panel B (2016-2017; P98-P100) and is a Member of the Royal Society Research System Committee (2019-present). Hardcastle was member (2014-2017) and chair (2018-2020) of the STFC PATT panel, chair of the e-MERLIN time allocation group (2007-2015), and NRAO peer review panel member (2018-2019) and XMM peer review panels (panel chair 2014-2015, panel member 2018-2019). He also participated in an STFC DTC review as panel member (2019) and served as a PPRP external expert (2018-2019). Jones reviewed NASA's Exoplanets Research Programme, assisted the selection of STFC-UKRI Global Research Challenges (2017-2018), was panel member on the NASA Emerging Worlds project (2016-2018) and in 2014 served on the STFC Project Review Board. Kaviraj sits on ESO OPC Galaxy Panel B. Kobayashi sat in 2017 on the Management Committee of EU COST Action "ChETEC: Chemical Element as Tracers of the Evolution of the Cosmos" (PI: R. Hirschi). Krause served twice on the INTEGRAL Time Allocation Committee (ESA) and is now a member of the STFC Ernest Rutherford panel (2020-). Lucas sat on the Subaru TAC (2017-2019) and on the STFC review committee for ESA M5 missions. Napiwotzki served on the STFC PATT TAG for the ING (2015-2018). Thompson sat on the UK Space Agency review panel as an ad hoc member for the ESA L3 LISA mission (2017-18) and served on the STFC Ernest Rutherford panel (Near Universe 2015-2017).

Fellowships and prizes: the Unit celebrates the achievements of its staff. Highlights of the reporting period include: Coppin was awarded a Royal Society Leverhulme Senior Research Fellowship (2019) and Devereux a Daphne Jackson Fellowship (2016). Geach gained an extension of his Royal Society University Research Fellowship (2018-2021). Hardcastle was recognised with Fellowship of the Institute of Physics (2013) and an ScD from Cambridge (2019). Kaviraj accepted a Visiting Scholarship at the IAP, Paris (2019). He was also part of the Galaxy Zoo team which was honoured in 2019 with an RAS Group Achievement Award. Stopford was a Green Gown Awards 2019 Finalist for his work on low-cost air quality monitoring. Łukowski held a Titchmarsh Fellowship (2013 – 2018) at the University of Oxford. Tiwari received a Junior Associate award in 2017 from the International Centre for Theoretical Physics (ICTP), Italy. PGR student Tracy Garratt was one of 3 recipients of the inaugural round of Bell-Burnell awards (2020).

Membership of Research Council or similar national and international committees: Brinks is a member of the nominating committee of the EAS. Hardcastle was a member of the e-MERLIN Steering Committee (2007-2015) and is a member of the UK SKA Science Committee (2019 to date) and one of the SKA Regional Centres (SRC) Working Groups (2020 to date). Sokhi served on an Expert Panel for the Hong Kong Environmental Protection Department, was member of a DEFRA's Air Quality Modelling Steering Group, (2014-2016) and sits on the Predictive Capability Working Group which falls under the Air Quality Strategic Evidence Leadership Group. He is Co-chair of the Science Advisory Group of the World Meteorological Organisations' Global Atmospheric Watch Urban Research in Environment and Meteorology (GURME) and Chair of WMO/GAW Air Quality Prediction and Forecasting Improvement for Africa (PREFIA). Thompson is the University Steering Board member for Development in Africa with Radio Astronomy network, serves on the UK Space Agency Herschel Space Observatory

Oversight Committee (2009-), and served on the STFC UK SKA Science Committee (2014-2017).

Invited keynotes, lectures, or conference chair roles: Unit staff served on the SOC of over 50 international conferences and presented 125 invited or keynote talks at international conferences or meetings. SOC chair or session convener roles include the following. Kaviraj: Unveiling the low surface-brightness Universe: the new era of deep-wide surveys, UK National Astronomy Meeting, Hull (Jul 2017); Galaxies Workshop at LSST@Europe 2, Belgrade, Serbia (Jun 2016); LSST Galaxies Workshop, Oxford, UK (2016); Galaxies at High Redshift and their Evolution over Cosmic Time, IAU Symposium 319 at the IAU General Assembly, Honolulu, USA, Aug 2015). Krause: workshop: “Superbubbles, HI holes and Supershells”, 10-12 November 2014, Freising, Germany; Splinter meeting J, “The Interstellar Medium”, Astronomische Gesellschaft, Bamberg, 22-26 September 2014. Smith: WEAVE-LOFAR conference in Oxford, March 2016. Thompson: Galactic Science with the SKA & its pathfinders, Lorentz centre workshop 2014. Jones: Photonics for Planets (Florence, 2014); Astrophotonics Summer School (Durham, 2015). Coppin: SMG20 – Twenty years of Submillimetre Galaxies (Durham, 2017). Hardcastle: Relativity at Work – Supermassive black holes, AGN and quasars, 30th Texas Symposium on Relativistic Astrophysics (Portsmouth, 2019). Forbrich: Orion (un)plugged, (Vienna, 2015); Cool Stars 20 (Boston, 2018); Regional VLBI Workshop (Mexico City, 2019); Orion uncovered (Leiden, 2019); Star formation across the Universe (Hatfield, 2020).

Peer review activities: Unit staff regularly carry out refereeing activities for high-profile journals such as Nature, Science, Nature Astronomy, Monthly Notices of the Royal Astronomical Society, Astronomy and Astrophysics, The Astrophysical Journal, The Astronomical Journal, Physical Review Letters, Journal of High Energy Physics, Communications in Mathematical Physics, Journal of Physics A: Mathematical and Theoretical, Atmospheric Chemistry and Physics, Quarterly Journal of the Royal Meteorological Society, Atmospheric Research, Climate Dynamics, and Optics Letters. They have reviewed grant proposals for the Royal Society and Royal Astronomical Society, as well as national research councils in the USA, Netherlands, Belgium, Austria, Italy, Germany, Poland, Canada, New Zealand, France, Estonia and South Africa.

Co-operation and collaborative arrangements for PGR student training: the University is one of the nine universities that comprise SEPnet which co-ordinates, among other things, joint postgraduate training in physics and astrophysics across the member institutions, including a recently launched Doctoral Training Network focussing on engagement with SMEs. Training events offered to SEPnet PGRs include its Winter and Summer Schools, a 2-day IOP/SEPnet event “Turning Science into Business”, an IOP/SEPnet event focussed on “Taking control of your career as a woman in physics”, and “Opportunities beyond your PhD”, in collaboration with the National Physical Laboratory and Skillfluence.

The Unit participates in the national EPSRC CDT in Aerosol Science. Each of the 10 PhD students at the University will partner with one of the Centre’s 45 industrial and public sector partners which include AstraZeneca, Defra, Dstl, the Environment Agency, Rothamsted Research, and the Met Office, in collaborative research programmes.