

## Unit-level environment template (REF5b)

<b>Institution: University of Portsmouth</b>
<b>Unit of Assessment: Physics</b>
<p><b>1. Unit context and structure, research and impact strategy</b></p> <p><b>1.1 Unit context and structure</b></p> <p>Based in the Faculty of Technology, our Institute of Cosmology and Gravitation (ICG) and School of Mathematics and Physics (SMAP) provide a vibrant and innovative physics research environment. During this REF period we have established new research groups in Gravitational-Wave Science and Quantum Information, won eight UK and EU fellowships and created seven new academic posts, building on our reputation as a world-leading centre in Cosmology and Astrophysics. This submission includes 21 category-A staff (up from 17 in REF2014), including seven Early-Career Researchers (ECRs), reflecting the vitality and continuing growth of physics at Portsmouth.</p> <p>The ICG has grown dramatically since it was established as a research institute in 2002. Supporting that growth and diversification, research is organised in four broad but interrelated groups overseen by the Institute Director:</p> <ul style="list-style-type: none"> <li>• <b>Theoretical Cosmology:</b> professors <i>Crittenden, Koyama, Maartens, Wands</i>; reader <i>Bruni</i>; senior lecturer <i>Assadullahi</i>; STFC Ernest Rutherford Fellow (ERF) <i>Noller</i>, starting in February 2021; research fellow <i>Gumrukcuoglu</i>.</li> <li>• <b>Observational Cosmology:</b> professors <i>Amara, Bacon, Crittenden, Nichol</i>; Royal Astronomical Society (RAS) fellow <i>Collett</i>.</li> <li>• <b>Extragalactic Astrophysics:</b> professors <i>Maraston, Thomas</i>; senior lecturers <i>Canning, Gaur, Whalen</i>; research fellow <i>Frohmaier</i>.</li> <li>• <b>Gravitational-Wave Science:</b> reader <i>Lundgren</i>; senior lecturers <i>Harry, Nuttall</i>, who holds a UKRI Future Leaders Fellowship (FLF).</li> </ul> <p>In 2018 we integrated all physics research in the university into the Faculty of Technology by establishing SMAP, which runs Institute of Physics (IoP) accredited undergraduate courses in Physics, Astrophysics and Cosmology. Physics research in SMAP focuses on:</p> <ul style="list-style-type: none"> <li>• <b>Quantum Information:</b> reader <i>Tamma</i>; senior lecturer <i>Goussev</i>.</li> </ul> <p>Additional SMAP academic staff are submitted to UoA10 (mathematical sciences), UoA11 (computing) and UoA12 (engineering).</p> <p>Portsmouth is a member of the South East Physics Network (SEPnet), a consortium of nine universities working together to share best-practice and promote excellence in research,</p>

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innovation and teaching. The network includes GRADnet – the largest postgraduate research school in England – as well as employer engagement, outreach and public engagement teams.

## 1.2 Strategic developments since REF2014

Our strategic objectives in REF2014 were:

**(i) To consolidate the ICG's position as an internationally-leading centre of research excellence in cosmology and astrophysics, and strengthen leadership roles in major international collaborations.**

Building on previous investments in the Sloan Digital Sky Survey (SDSS) and the Dark Energy Survey (DES), the ICG has secured a unique position spanning the range of upcoming experiments (see 'Infrastructure' in Section 3 and 'Leadership Roles' in Section 4). In 2015 we became institutional members of what is now the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST) collaboration. *Percival* and *Nichol* led the 2015 UK buy-in to the Dark Energy Spectroscopic Instrument (DESI), securing participant status for four ICG staff members plus associated postdocs and students. These investments helped win four new European Research Council (ERC) grant awards in this REF period under Principal Investigators *Beutler*, *Collett*, *Koyama* and *Percival*, as well as UKRI grant funding. Following *Percival's* departure to a Research Chair in Canada in 2018, we appointed *Amara* (Royal Society Wolfson Fellow) in 2019 to reinforce our leadership in large surveys, including LSST and the European Space Agency (ESA) Euclid satellite.

We identified gravitational-wave (GW) science as a rapidly developing area, synergistic with our existing strengths in survey astronomy and gravitation, and established a new research group supported by University investment (REF5a paragraph 1). We appointed *Lundgren* as reader in 2017, followed by *Harry* and *Nuttall* in 2018 as senior lecturers, alongside a research fellow. Our GW team plays a pivotal role within the Laser Interferometric Gravitational-Wave Observatory (LIGO). We joined the LIGO scientific collaboration in 2018 and led the detector characterisation working group and all-sky search group, developing one of the main analysis toolkits used within the LIGO/Virgo collaborations (PyCBC). This has resulted in STFC research grant awards, which have funded three postdocs, a citizen science project and a UKRI FFL. The 16 research outputs in Gravitational Waves submitted in this REF demonstrate the quality of the research, constituting 32% of our total outputs.

To enhance synergies with astronomical transient surveys, we have appointed *Graur* (supernova astrophysics) and *Collett* (strong gravitational lensing) to permanent academic positions. In 2017 we established the transients participation group (TiDES, founding PI *Nichol*), one of ten major surveys in the European Southern Observatory (ESO) 4-metre Multi-Object Spectroscopic Telescope (4MOST) consortium. In 2019 we became partners in the Gravitational-Wave Optical Transient Observatory (GOTO) collaboration, whose aim is to identify optical counterparts to GW events. Contributing a further 6 research outputs, this research is supported by a research fellow in data-intensive science, an STFC-funded postdoc, and an RAS fellow (*Collett*), who became a Royal Society University Research Fellow (URF) in October 2020.

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A total of 34 outputs in this REF2021 submission derive from on our involvement in large international astronomy surveys, accumulating more than 20,000 citations according to the Web of Science database. Clarivate identified three Portsmouth researchers (*Nichol, Percival, Thomas*) as Highly Cited Researchers 2020 in their analysis of the most influential researchers in space science over the past decade, an achievement matched only by Durham in the UK.

**(ii) To support research exchanges, visits and collaborations, encouraging fellowship applications of the highest calibre.**

To attract outstanding postdoctoral researchers and provide a stepping-stone into longer-term positions, we established a programme of three-year Dennis Sciama (DS) Fellowships in 2015, further expanding our international network. All of our DS fellows have moved on to senior fellowships or permanent academic positions since their fellowships, including an STFC ERF, Royal Society URF and UKRI FLF.

We support an active visitor programme that currently includes 16 visiting research fellows. We hosted the National Astronomy Meeting in 2014, the 30th Texas Symposium on Relativistic Astrophysics in 2019 and numerous collaboration meetings (see Section 4). Our DS fellowship programme, extensive international engagement and unique position in major surveys have resulted in seven national fellowship awards (3x Royal Society, 1x Leverhulme, 1x RAS, 1x STFC and 1x UKRI) and one EU Marie Skłodowska-Curie fellowship. We also appointed a Global Challenges champion to identify collaboration and funding opportunities, and won funding for international collaborations and training in South Africa (STFC award), China and Thailand (Royal Society Newton Advanced Fellowships).

**(iii) To grow and diversify sources of external funding.**

Our annual research income over the current REF period grew by 21% compared with REF2014 (see Section 3). We have developed interdisciplinary and intersectoral links to diversify our sources of funding. The growth of our SMAP undergraduate programmes has enabled us to establish a Quantum Science and Technology Hub (QSTH) aligned with EPSRC research themes as part of the national quantum landscape. University investment supported our appointment of a Data-Intensive Science Fellow (*Frohmaier*) who has applied data analysis techniques from astronomical research to interdisciplinary projects. These include collaborations with Oxford University Hospitals on the early detection of skin cancer and with Kings College Hospital NHS Foundation Trust to develop a web-based diagnostic tool for cardiac arrests.

We contribute to university-wide thematic research areas (REF5a paragraph 9), including *Future and Emerging Technologies, Health and Wellbeing* and *Sustainability and the Environment*. *Bacon* is co-investigator on the Portsmouth work-package in the UKSA-funded CommonSensing project, helping Pacific island nations build climate resilience through satellite technology. *Lundgren* is working with the Centre for Applied Geosciences in the Faculty of Science and Health, pioneering the use of GW data-analysis techniques on acoustic data from rock fracture experiments, leading to a grant application to EPSRC. *Lundgren* also led a Research England E3 bid with researchers from the Faculty of Science and Health to develop accelerometer arrays and seismic sensor technology.

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**(iv) To maximise the impact of our physics research.**

To assist our researchers to develop the impact of their research, we appointed an STFC Innovation Partnership Scheme fellow (0.4FTE) who works with the university's Research and Innovation (R&I) Services (REF5a paragraph 57) and SEPnet to establish a framework of initiatives and activities connecting researchers with businesses, local councils and charities. We have also upgraded our outreach officer role into a senior Outreach and Public Engagement (OPE) Fellow (1.0FTE) to develop and deliver a more strategic OPE approach, overseen by our OPE Champion (formerly *Masters*, now *Nuttall*).

Our impact and public engagement strategy has five strands:

- **Engagement with school children:** We have conducted repeat interactions with 1,400 school pupils (aged 9 to 15) at targeted secondary schools and their feeder primary schools, delivering workshops and activities to increase pupils' interest, enjoyment and participation in physics.
- **Engagement through large events:** Our OPE team supports researchers in developing new and innovative activities for large events and festivals. Since 2013 our research has influenced over 53,000 members of the public and schoolchildren at events including our annual Stargazing event at Portsmouth Historic Dockyard and the UKSA 'Principia Schools Conference' with astronaut Tim Peake in 2016.
- **Engagement through citizen science:** We have over a decade of experience with online citizen science projects, including Galaxy Zoo and Zooniverse (where we are one of only two UK universities with institutional membership). Our citizen science and outreach fellow (1.0FTE) provides dedicated Zooniverse development and support, enabling millions of people worldwide to engage with more than 70 active projects. We report this success as one of our Impact Case Studies (REF3UoA9Zooniverse).
- **Engagement with visually-impaired children:** Our visually-impaired outreach and public engagement fellow (1.0FTE) developed the award-winning Tactile Universe, which makes astrophysics research accessible to the blind and visually-impaired community. The project works with primary and secondary school children and external outreach professionals. It has also developed significant international connections, including in South America (funded by the IAU Office of Astronomy and Development). We report this multi-award-winning project in our second Impact Case Study (REF3UoA9TactileUniverse).
- **Industrial and public-sector engagement through data science:** We have built a portfolio of strategic impact activities with external partners, using data-intensive skills to address Grand Challenges in the UK Industrial Strategy of Growing Artificial Intelligence and the Data-Driven Economy. We have a programme of PhD placements (including placements with Royal Bank of Canada, STFC and Quant Foundry) and postdoctoral projects (including analysis of environmental, smart meter, cardiovascular, oncological and COVID-19 data, see REF5a COVID-19 annex).

### 1.3 Future strategy

Our future R&I strategy has six key elements:

1. **We will continue to develop the ICG as a world-leading centre for cosmology, astrophysics and gravitational-wave research.** We will achieve this through the combined analysis of observational data, coming from multiple experiments, including Euclid, DESI, LSST, LIGO and the Square Kilometre Array (SKA). Our multi-wavelength and multi-messenger approach will focus on the interface between theory and observation, building on previous investments in appointments and facilities. With leadership roles in major international collaborations, our unique position across the range of upcoming experiments will deliver highly-cited research outputs and competitive grant funding (REF5a paragraph 60). This will include STFC, UKSA and ERC grants, as well as UKRI and Royal Society fellowships, enabling us to sustain a vibrant research environment, capable of attracting outstanding staff and students.
2. **We will develop our expertise in data analytics and software engineering to become a leading centre for advanced analytical techniques.** To achieve this we will develop state-of-the-art tools to apply advanced statistical techniques and machine learning to datasets in astronomy and cosmology, enhancing our core research strengths and funding. We will deploy this expertise and infrastructure to support multidisciplinary projects with researchers across the university Thematic Areas (REF5a paragraph 9), broadening the range of research outputs, impacts and sources of funding. We will develop joint research grant applications aligned with priority areas for research funders, including EPSRC, NERC and NIHR.
3. **We will grow experimental physics research in SMAP** through new appointments in quantum optics and material science, leveraging and expanding cross-faculty facilities (the QSTH and an Advanced Materials Laboratory). Building on existing collaborations, including with NPL, DSTL, IBM and the Quantum Metrology Institute, we will address priority challenges in energy, the environment and advanced technologies.
4. **We will exploit new opportunities in fields including quantum technologies and space science to diversify our physics impact.** To achieve this we will build on our current expertise in large European Space Agency scientific missions, including Euclid and LISA, and collaborations with other Portsmouth researchers, e.g. the Global Earth Modelling project. We will work with the university Thematic Areas (REF5a paragraph 11) and the university-led South Coast Centre for Excellence in Satellite Applications (REF5a paragraph 17) to provide services for industry and the public sector in quantum sensing and advanced image analysis, utilising our expertise in machine learning and citizen science.
5. **We will grow our innovation, outreach and public engagement work, in collaboration with our SEPnet partners.** We will expand our long-term strategic engagement with local schools to their wider communities, developing pupils' and their families' science capital through regular engagement. We will also work with our SEPnet partners to collect evidence of impact, shaping OPE policy in our region and beyond, and

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continue to develop links with businesses and public bodies (including hospital trusts and local authorities), building up a portfolio of joint projects. We will broaden the experience and perspectives of our staff and students through our growing number of placements.

6. **We will demonstrate our commitment to equality, diversity and inclusion through our actions.** By embedding equality and diversity in all our activities and promoting best practice, we will progress from our current Athena Swan bronze award to silver by 2025 (REF5a paragraph 44). We will identify, recruit, develop and retain top researchers reflecting our diverse society (REF5a paragraph 29), and provide research opportunities for BAME students through placements and studentships.

#### 1.4 Open research strategy

Research outputs are made freely available via arXiv.org. We ensure all publications are deposited on the university repository (Pure) within three months of acceptance, in line with UKRI and university policies (REF5a paragraph 24). Compliance is monitored by our academic Open Access (OA) lead, and supported by administrative staff. As a result, OA compliance rates rose from 83% in 2016 to 95% in 2020.

Our outputs include a data availability statement on Pure, with over 98% compliance since 2018. We also make our research data available via our collaborations. Our surveys, including SDSS, LIGO/Virgo and DES, are committed to releasing and archiving data for the broader scientific community, and provide the information and tools required. For example, our researchers created public galaxy catalogues for SDSS Data Release 16 (MaNGA and eBOSS FIREFLY).

Software developed by Portsmouth researchers is made freely available online. Examples include PyCBC, a primary analysis toolkit used within the LIGO/Virgo collaborations; FIREFLY, a fitting code for deriving stellar population properties; MaStar Stellar Population Models, which predict the spectral energy distributions of stellar population models; MG-PICOLA, a modified gravity N-body simulation code; and SONG, a Second-Order Non-Gaussianity Einstein-Boltzmann code.

#### 1.5 Research culture

We support and encourage our researchers to perform at the highest international level, actively developing the next generation of research leaders. Consequently, our staff have produced agenda-setting research (demonstrated in our REF2021 outputs) and assumed leadership roles (see Section 4) spanning science collaborations, learned societies, Research Councils and the university (including the role of Pro Vice-Chancellor R&I).

In 2017, the ICG drafted and adopted a Code of Conduct that commits us to actively pursuing a positive, respectful and courteous attitude, rejecting harassment, bullying and unethical practices, cultivating an environment where everyone feels valued and encouraged in their work. We also appointed a Dignity and Respect Champion to promote good practice and help resolve issues informally whenever possible. 93% of ICG staff in the Race Equality Charter Staff Survey 2019 (response rate 41%) reported that their work environment clearly communicates that inappropriate language or behaviour are unacceptable.

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We ensure all R&I activities undergo an ethics review (REF5a paragraph 23).

## 2. People

### 2.1 Staffing Strategy and Staff Development

#### 2.1.1 Staffing and recruitment policy

Strategic university investment funded new senior appointments to strengthen our research leadership in two key areas (REF5a paragraph 1): gravitational-wave science and observational cosmology. We appointed *Lundgren* as a reader in our new gravitational-wave group in 2017, followed by *Harry* and *Nuttall* as senior lecturers in 2018. *Amara*'s appointment as Professor of Cosmology in 2019 reinforced our leadership in large astronomical surveys.

We aim to attract exceptional Early-Career Researchers (ECRs) from around the world, then encourage and support their development into more senior roles. For example, six current SDSS working-group chairs and four DESI key-project convenors are current or former Portsmouth postdocs. Seven of our 21 category-A staff submitted are ECRs, and nine hold non-UK citizenship.

As a result of our commitment to developing and promoting our staff, many of our established academic staff are now in senior positions with significant management responsibilities. To ensure the continued vitality and sustainability of our research groups, we have appointed senior research fellows to proleptic lectureships in cosmology (*Noller*, arriving in 2021, and *Collett*) and as senior lecturers in extragalactic astrophysics (*Canning*, *Graur* and *Whalen*).

In line with the university's commitment to supporting and retaining outstanding people, 96% of our submitted staff now hold permanent positions (up from 71% in REF2014), including all 18 academic staff. We have also maintained our record of appointing all senior research fellows to proleptic lectureships starting at the end of their fellowships (REF5a paragraph 32), including one STFC ERF and two Royal Society URFs in this REF period.

We cultivate a balance between postdoctoral research staff working on UKSA, STFC and EU funded projects and more experienced staff on individual externally-funded and internally-funded fellowships. Dennis Sciama (DS) fellowships were established to provide a stepping stone for experienced postdoctoral researchers towards long-term fellowships or permanent academic positions; all of our DS fellows have since gone on to senior fellowships or faculty positions. To avoid short-term contracts, we routinely use university funding to extend or underwrite postdoctoral appointments while grant renewals are pending, enabling us to recruit and retain the best research staff.

#### 2.1.2 How we support staff at the beginning of their research career

We help ECRs to build research teams through a range of support mechanisms (REF5a paragraph 41), including workload allocations, PhD student and postdoctoral support, and roles

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in international collaborations that include significant institutional investments (such as LSST and GOTO, see Section 3). All new PhD supervisors – including ECRs starting out as second and third supervisors – are required to take university training (REF5a paragraph 38). To help with fellowship and ERC grant applications, we also provide staff with internal peer-review support and mock interview panels.

To facilitate new staff members' integration, we encourage them to give presentations at our weekly lunchtime seminars to introduce themselves and their research. Alongside their membership of the university Research Staff Forum (REF5a paragraph 42), postdocs also elect a representative on the Faculty R&I Committee, and have a representative on the ICG management committee.

Of 38 postdoctoral research staff leavers in this REF period, 14 successfully progressed to faculty roles at institutions around the world, including China, France, Germany, Norway, Poland, Spain, the US and the UK. Another five secured long-term fellowships in Denmark, Portugal, Spain and the UK.

### **2.1.3 Staff development strategy for staff pursuing a career in research**

We ensure all newly appointed academic and research staff have induction meetings with their line manager, to identify and address their training needs. These are followed up with regular review meetings. In addition, we assign new academic staff and all research staff a mentor (REF5a paragraph 37), independent of their line manager, to facilitate their integration into the department and provide support and career advice.

As part of our commitment to supporting their development, all staff undertake an annual Performance and Development Review (PDR) with their line manager, to discuss research plans and career goals, and identify training needs for the coming year (REF5a paragraph 53). In the latest (2019) staff survey, 100% of ICG staff reported having a PDR within the past 12 months. University training includes a Research Leader development programme involving coaching, work-shadowing and a three-day workshop. We encourage female staff to apply for Advance HE's Aurora leadership programme (REF5a paragraph 35) and support this with workload allocations. Two recent participants both reported that the programme supported their academic career progression.

A university sabbatical scheme was introduced in 2016 (REF5a paragraph 36) to allow staff to take paid leave for research or innovation, open to all academic staff (including fixed-term and part-time staff). *Nichol* was awarded a sabbatical in 2017 to build research collaborations and *Bruni* won a sabbatical in 2019 to deliver the Texas Symposium.

### **2.1.4 Recognition and reward for R&I**

Our principal mechanism for recognising and enabling research and impact activities is the workload allocation (REF5a paragraph 53), which is a transparent and detailed work plan published each year. Research-time allocations are determined in line with faculty guidelines and include time for impact, outreach and public engagement activities. We empower line managers to recognise exceptional performance and contributions through recognition awards



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and nominations for the annual Vice-Chancellor's Awards for Excellence (REF5a paragraph 55). Our OPE fellows won Vice-Chancellor's Excellence awards in 2018 and 2020.

We recognise and reward staff for excellent and impactful research leadership through promotion. Our promotion process is run annually, with workshops and mentoring available to help all staff develop their applications (REF5a paragraph 54). Since 2014, we have promoted *Bacon* and *Tamma* to reader, and *Bacon*, *Koyama*, *Maraston* and *Thomas* from reader to professor.

### 2.2 Research Students

We recognise postgraduate research (PGR) students as vital contributors to our research environment, underpinning our reputation as an internationally-leading centre of excellence. We have a total of 29 current PhD students, with 39 students completing their PhDs during this REF period (up from 28 in REF2014). 95% of our PGR students reported satisfaction with their overall research degree experience in the latest Postgraduate Research Experience Survey (PRES2019, response rate 69%).

As well as attracting first-class students from universities across the UK, our strong international profile enabled us to recruit exceptional international students. Of 39 students completing their PhDs in this REF period, 13 were non-UK nationals. However, only 6 of those students (15%) are female, while 7 of our current PGRs (24%) are female, highlighting the need to broaden the diversity of those we recruit.

We fund our studentships through a combination of STFC doctoral training grants, ERC and Royal Society grants, and university bursaries (REF5a paragraph 63). In 2017, STFC also funded a Data-Intensive Science (DISCnet) doctoral training collaboration with SEPnet partners from Sussex, Southampton, QMUL and the Open University, with further funding announced for 2020. The remainder of our studentships are funded by national scholarships, e.g. Thai government scholarships.

Our STFC-funded PhD students are guaranteed 3.5 years of support, and extension requests may be submitted in the final year to enable students to complete their thesis. We recently approved all requests by students, within the final 12 months of completion, for funded extensions due to disruption caused by the COVID-19 pandemic (REF5a COVID-19 annex).

#### 2.2.1 Monitoring, support, progress and completions

Underpinned by our commitment to student progress and development, we have a 100% completion rate during this REF period. Our PGR recruitment, progression and assessment are overseen by a postgraduate tutor, with students required to submit a Major Review report at the end of their first year and pass a mini-viva with two independent assessors to progress. Subsequently students submit an Annual Review to summarise progress and set goals and objectives.

To support their progress, we allocate PhD students a three-person supervision team, including external supervisors where they bring additional expertise. This joint supervision strategy provides independent support for students and encourages synergistic connections and

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collaborations. Our PGRs and their supervisors meet at least weekly. 100% of our students in PRES2019 said that their supervisors had the skills and subject knowledge required to support their research, and 95% said they had regular contact with their supervisor and feedback that helped direct their research.

To meet our students' training needs we provide a core lecture programme in their first semester and offer short specialised courses in the second semester. According to PRES2019, 95% of our students reported developing their ability to apply appropriate methodologies during their PhD. To facilitate their progress and development, we allocate each student a research training budget of £3.5k to attend relevant schools and conferences, and supplement this with additional fieldwork funding for observing trips or collaboration meetings. We encourage STFC-funded students to apply for funding for specialised training via long-term attachments with research collaborators (recent examples include placements in Madrid and Aachen). 95% of our students in PRES2019 reported developing contacts and professional networks through their PhD.

**2.2.2 Skills development and career preparation**

Our university Graduate School development programme supports and enhances our students' academic and professional skills (REF5a paragraph 38). We expect students to complete the Graduate Skills Professional Development programme during their first year to develop their pedagogical skills and provide a route to become HEA Associate Fellows. Students also participate in GRADnet (the SEPnet graduate training network) to gain technical, professional and leadership skills, and receive outreach training from our Outreach and Public Engagement senior fellow. DISCnet students are trained in the latest skills for the rapidly growing data economy through workshops and online DataCamp modules.

We provide access to careers advice through our university careers and employability service and SEPnet workshops. Alongside senior staff talks on academic careers, former students and postdocs present talks on their career paths. We offer all PGRs three-month paid placements, through SEPnet and DISCnet, providing an opportunity to broaden their skills and career perspectives (*Nichol* was chair of the DISCnet placements committee). Students suspend their studies during the placement. Recent examples include projects with Oxford and King's College Hospital Trusts, Quant Foundry (quantitative solutions), Earth-i (geospace intelligence) and Madgex (career software and services).

Recognising the intense competition for postdoctoral positions that new PhD graduates face, we initiated a programme of 4-month research associate positions in 2020. Modelled on the STFC Studentship Enhancement Programme fellowships offered in 2014/15, these positions are available to recently completed PhD students to maximise the scientific output from their PhDs (via research or impact projects) and boost their research careers.

The success of our academic training and career preparation is demonstrated by the fact that 15 of our 39 PhD graduates in this REF period went on to postdoctoral positions at institutions worldwide. Examples include Yale, Max Planck (Garching), Swinburne, Kyoto, Barcelona, Imperial College, QMUL and Manchester. Other graduates have progressed into diverse

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professions, including finance, software engineering and teaching, with increasing numbers entering data analytics, in industry and the public sector.

**2.3 Equality and Diversity**

Our commitment to promote gender equality was recognised by the ICG's receipt of an Athena Swan Bronze award in 2015 (renewed October 2019). We aim to achieve a silver award by 2025 (REF5a paragraph 44). The School of Mathematics and Physics will be applying in 2021.

In 2020 the ICG extended the scope of its Athena Swan team to become an Equality, Diversity and Inclusivity committee. Chaired by the ICG Associate Director, the committee includes representatives from academic, research, professional and support staff and research students. We established a reading group which meets monthly to better educate ourselves about race and ethnicity. All staff undertake equality and diversity training, including unconscious bias training (REF5a paragraph 47), which is reinforced by departmental events and seminars. In our 2019 staff survey, 93% of ICG staff reported that the university's equality and diversity policies were made clear to them.

Of our 21 staff submitted, three (14%) are female with the same proportion categorised as BAME. These proportions are consistent with the wider pool of research and academic staff in physics at Portsmouth (19% female and 19% BAME), reflecting the lack of diversity in research and academic staff in physics nationally. To address this, our recruitment and selection panels all include a trained interviewer and female staff members, and we give workload allocations to female staff to recognise and offset the additional demands that this places on them. Our selection panels encourage qualified applicants from under-represented groups, short-listing at least one female candidate for all posts, or reporting to the EDI committee why this was not possible. The Athena Swan self-assessment team monitors gender balance at all stages of recruitment, career progression and staff turnover. The mean and median gender pay gap for staff submitted is 7% and 19% respectively, compared to 17% and 14% for all research and academic staff in physics at Portsmouth – reflecting the smaller proportion of women in senior roles. One submitted staff member (5%) declared a disability, consistent with the sector average.

Recent physics staff members on maternity leave have benefitted from 'keep-in-touch' days and flexible working arrangements on their return. We have also secured external funding to support childcare expenses associated with conference attendance, successfully lobbying the university to change regulations to allow the payment of childcare expenses for conference attendance.

Our department heads actively promote flexible working (REF5a paragraph 46), with 93% of ICG staff reporting in the 2019 staff survey that their line manager supported flexible working. Of our 21 staff submitted, four benefit from formal flexible working arrangements, including part-time hours. We have also instituted flexible working arrangements during the COVID-19 pandemic to help staff with additional caring responsibilities. Line managers and supervisors have kept in regular contact with their staff and research students throughout, providing additional support where needed.

We require all staff involved in REF output selection to complete REF-specific equality and diversity training (REF5a paragraph 50). We follow the university's REF2021 Code of Practice to

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identify staff with significant responsibility for research, assess research independence and select outputs. The average number of outputs selected in this UoA from category-A female staff (3.0) was higher than from male staff (1.9), while the average number of outputs from category-A BAME staff (1.7) was slightly lower than the average for all category-A staff (2.0) or for staff with self-declared disabilities (2.0). However, these differences are not statistically significant given the small numbers involved.

### 3. Income, infrastructure and facilities

#### 3.1 Research funding and strategies for generating research income

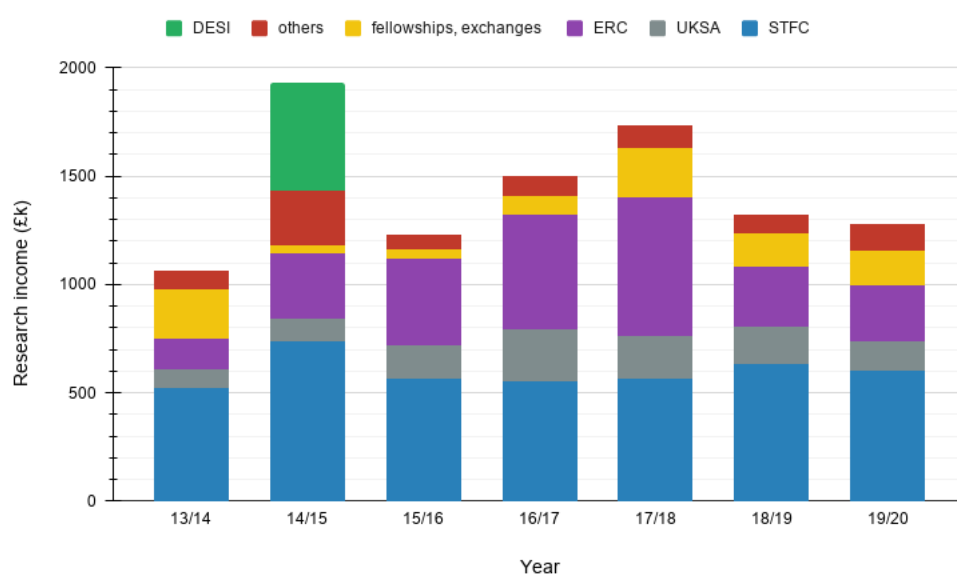


Figure 1: Annual research income by funding category

Our total research income grew from £7.1M in REF2014 to £10.1M in the current REF period, with a 21% increase in annual income. Figure 1 shows the breakdown in different funding categories. Note that COVID-19 delayed expenditure on some grants in 2019/20.

Our strategic investment in staff and facilities (REF5a paragraph 63), including establishing a new research group in gravitational-wave science, has led to steady growth in our core STFC funding. Our **STFC consolidated-grant** awards have risen significantly over this REF period from £1.4M in 2013-16 to £1.6M in 2016-19 and £2.1M in 2019-22, despite flat-cash funding nationally, and increasingly intense competition. All of our **STFC new applicant awards** in this REF period were successful, including *Masters* (2015), *Whalen* (2017), *Harry* (2020) and *Nuttall* (2020), totalling a further £466k.

Our strategic investment in astronomical surveys (REF5a paragraph 67) provided the platform for winning substantial European funding, including two **ERC consolidator grants** (€2.2M 'Dark Survey' grant, 2014-18; €1.7M 'Cosmological tests of gravity' grant, 2015-21), and two **ERC**

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**starting grants** (€1.1M 'Fundamental Physics from the large-scale structure of the Universe' grant, 2020-2025; €1.8M 'Statistical era of strong gravitational-lensing cosmology' grant, 2021-2026). Recent awards guarantee continued ERC funding until 2026.

**UKSA** and **Royal Society** grants are linked to our leadership in major surveys including **Euclid** (UKSA awards totalling £1.3M) and **DESI** (totalling £653k). Smaller grants have supported **DES**, the extended Baryon Oscillation Spectroscopic Survey (**eBOSS**, part of SDSS), and the ESA **LISA** mission.

Our reputation as a world-leading research centre and unique position in major surveys has attracted outstanding fellowship applications and successes (REF5a paragraph 32), including **STFC Ernest Rutherford Fellowships** (*Beutler*, 2017-18, *Collett*, 2021-26), **RAS Research Fellowship** (*Collett*, 2020-21), **Royal Society Wolfson Fellowship** (*Amara*, 2019-24), **Royal Society University Research Fellowships** (*Beutler*, 2018-20, *Collett*, 2021-26), **UKRI Future Leaders Fellowship** (*Nuttall*, 2020-27), and an EU **Marie Skłodowska-Curie Fellowship** (*Nadathur*, 2015-17).

**Royal Society grants** have supported collaborations in the USA and Australia (*Collett*), China (*Percival*) and Thailand (*Wands*). **SA-DISCnet** (2018-2019) utilised our expertise in developing data-science training in collaboration with our research network in southern Africa.

New appointments and investments in innovation have attracted new sources of income. Grants from the **U.S. Office of Naval Research** (\$317k, 2018-21) and **U.S. Army Research Lab** (\$50k, 2017-18) support our quantum information group. In addition, STFC innovation awards have come from an **Impact Accelerator Account** (£120k, 2019-21) and research grant 'Developing synergies between transient astronomy and early medical intervention' (£71k, 2018-19).

Our public engagement work has won STFC funding through our latest consolidated grant (including a citizen science project, 'Gravity Spy', based on our GW research) and also through nucleus and follow-on awards for the Tactile Universe project (£10k in 2016-18, £51k in 2018-20 and £7k in 2020-22).

### 3.2 Organisational infrastructure supporting research and impact

Building on previous investments in SDSS and DES, the ICG has strategically invested in the next generation of astronomical surveys (REF5a paragraph 63). Alongside our creation of a new gravitational-wave group, we have targeted major investments towards fostering collaborations between cosmology, astrophysics and GW groups, preparing for multi-wavelength and multi-messenger surveys. These investments include:

- Institutional membership of the **Vera C. Rubin Observatory project** to conduct the ten-year **Legacy Survey of Space and Time** (LSST): \$25k per year for ten years (2015-25).
- Membership of the **Time-Domain Extragalactic Survey** (TiDES) transient science team (part of the 4MOST consortium), contributing to the design and operation of a transient survey linked to the LSST's science goals and data stream: €200k (2017).

## Unit-level environment template (REF5b)

- Institutional membership of the **Gravitational-Wave Optical Transient Observatory** (GOTO), providing Portsmouth staff and students with full access to GOTO data, working groups and authorship: £200k (2019).

The ICG runs a dedicated high-performance computing cluster ('SCIAMA') with 3700 cores. SCIAMA plays a vital role in our exploitation of large astronomical surveys, supporting the production of large galaxy mock catalogues and advanced statistical analyses of large datasets. Commissioned in 2010 with joint funding from **SEPnet**, it has been upgraded several times since, including additional nodes purchased with **ERC** funding in 2015 (SCIAMA-III). A 2019 strategic university investment (£300k) paid for a major upgrade (SCIAMA-IV), providing an additional 896 cores with 8.4TB of distributed memory (REF5a paragraph 64).

The ICG's Research Software and Data Specialist (1.0FTE) and Senior Specialist Technician (1.0FTE) provide technical and specialist support for SCIAMA and its users. In addition, our citizen science and outreach fellow (1.0FTE) provides expertise supporting research and impact projects in citizen and data science, especially data-handling and curation.

As a member of **SEPnet-III**, the university has committed £175k per year over five years (2018-23) – including £35k annual membership fee, plus in-kind commitments – to support employer engagement, research, impact and public engagement activities. We have a SEPnet-funded seminar room for graduate lectures and video-conferencing. SEPnet publishes an online list of infrastructure and equipment available to all partners.

### 3.3 Operational and scholarly infrastructure

The ICG administrative office has 1.5FTE support staff, including a full-time institute manager with financial training and experience of research grant applications and management. Researchers also work closely with professionals in the university research finance office.

Our investment in computing and IT resources ensures a high standard of computing equipment for all physics researchers. In 2020, newly-furnished offices were made available for SMAP staff and students so that all our physics researchers benefit from modern, well-equipped offices co-located in the purpose-built **Dennis Sciama building**. In PRES2019, 100% of ICG research students reported that they had a suitable working space.

### 3.4 Equality and diversity

Our staff fully engage with equality and diversity actions in international collaborations such as the **Committee On INclusion** (COINS) in **SDSS**, to ensure equal access to these collaborations. For example, *Canning* is a member of the **DESI Diversity, Equality and Inclusion committee** and *Nuttall* is a **LIGO/Virgo collaboration ally**, part of an initiative to foster an inclusive environment within the collaboration. We advertise codes of conduct for meetings that we host. In the case of the **Texas Symposium**, we named members of the local and scientific organising committees as points of contact for anyone with concerns, which were then fully addressed.

## Unit-level environment template (REF5b)

**3.5 Support for impact activities**

We appointed an **Innovation Partnership Scheme Fellow** (*Prosser*), with initial funding from STFC, to foster relationships with external organisations, support PGR placements, and provide entrepreneurship training to PGRs and ECRs. University investment has also enabled the appointment of a **Research Fellow in Data-Intensive Science** (*Frohmaier*), who supports impact activities and interdisciplinary research through his expertise in advanced statistical techniques and machine learning. In addition, the ICG's **Senior Outreach and Public Engagement Fellow** (*Gupta*) leads our strategic plan for public engagement, supported by the OPE team (including *Bonne* and *Krawczyk*).

**3.6 Use of major facilities**

Our researchers have benefited from the use of major astronomy facilities valued at £320k over this REF period, including highly competitive time awarded on the **European Southern Observatory Very Large Telescope** (valued at £280k) and the **Hubble Space Telescope** (£13k). Use of these facilities supports and exploits our involvement in major surveys, providing follow-up observations of data from surveys such as SDSS-IV and DES data, including gravitational-lens candidates and transients.

**4. Collaboration and contribution to the research base, economy and society****4.1 Support for research collaborations, networks and partnerships**

As a result of our strategic investments to secure early involvement in major international surveys such as **SDSS** and **DES**, Portsmouth researchers have played leading roles in a wide range of collaborations:

- *Nichol* was a member of the MaNGA steering and coordination group (2011-15)
- *Maraston* was a member of the SDSS-IV Advisory committee (2012-16)
- *Masters* is spokesperson for the SDSS collaboration (since 2017)
- *Thomas* was the MaNGA Science Team chair (2014-17) and a member of the SDSS-IV collaboration Science Committee. He is currently on the SDSS-IV Advisory Committee and Data Products Committee.
- *Bautista* (PDRA) is eBOSS Lead Data Scientist within SDSS-IV
- *Amara* is chair of the Collaboration Meeting Steering Committee for DES
- *Bacon* is magnification analysis team lead and management committee member for DES
- *Nichol* was a member of the management and science committees for the DES (2007-18).

## Unit-level environment template (REF5b)

Based on our success in establishing leadership in current surveys, we have also expanded our involvement in the next generation of major surveys (such as **Euclid**, **DESI**, **LSST** and **SKA**) through both university investment and STFC/UKSA funding. This strategy has paid dividends, with Portsmouth researchers securing leading roles in these surveys:

- *Nichol* is a member of the ESA Euclid Science Team and Consortium Board
- *Beutler* was co-chair of the galaxy clustering working group in Euclid, a role formerly held by *Percival*
- *Nichol* was co-convener of the DESI time-domain working group, and was succeeded by *Graur* (then at Harvard)
- *Canning* is a co-convener of the galaxy and quasar physics working group in DESI
- *Amara* is a member of the LSST:UK executive committee
- *Bacon* is an LSST:UK board member and LSST:UK Science Liaison with SKA
- *Collett* is convener of the LSST-Dark Energy Science Collaboration strong lensing analysis working group
- *Nichol* is LSST:UK Science Liaison with Euclid
- *Bacon* is the SKA Cosmology Science working group Synergies lead, and UK SKA Science Committee chair
- *Maartens* holds a South African SKA Research Chair (2011-20).

We have also successfully developed a new research activity in gravitational waves, establishing the Portsmouth group as a key player in the international GW community and enhancing UK leadership in major experiments:

- *Harry* is one of two main contributors to PyCBC, one of the main analysis toolkits used within the **LIGO/Virgo** collaborations, and co-chair of the **LIGO/Virgo** all-sky searches for compact binary mergers working group
- *Nuttall* is co-chair of the **LIGO/Virgo** detector characterisation working group, a role formerly held by *Lundgren*
- *Harry* is co-chair of the **LISA** data-analysis tools work-package
- *Nuttall* is on the **GOTO** steering committee.

*Wands* is a member of the international **Particle Data Group** collaboration that produces the *Review of Particle Physics* which attracts more than 2000 citations annually.

We have hosted numerous collaboration meetings and workshops in Portsmouth, including the **UK Cosmology** workshops (June 2014, April 2017), **BritGrav** (April 2018), an international



## Unit-level environment template (REF5b)

cross-theme workshop on **Quantum Sensing Technologies** (April 2019), **Bayesian inference in GW astronomy** (May 2019) and the Portsmouth Workshop Series: **The Quantum Industry** (November 2019). In 2017, ICG researchers established a series of **South Coast Cosmology** workshops, held biannually with researchers in Sussex and Southampton, with the latest event being hosted online by Portsmouth in October 2020.

International visitors since 2014 include **Leverhulme Visiting Research Professor** (*Bershady*), **Royal Society Newton Advanced Fellowships** (*Zhao* and *Gumjudpai*), as well as national fellowships from Germany, Brazil, Italy and Japan. In addition *Pogosian* (Simon Fraser University, Vancouver) and *Zhao* (National Astronomical Observatory China, Beijing) both hold senior visiting positions at the university and are regular visitors.

#### 4.2 Engagement with key research users and wider contributions to the society

Our appointment of an **Innovation Partnership Scheme Fellow** facilitated collaborative innovation projects with numerous external organisations. For example, we ran Deep Data Dives (data hacks) with external partners including Hampshire County Council, Portsmouth City Council, and the Royal National Lifeboat Institute. Our project with SSE analysed time-series data from smart meters using an algorithm developed for transient astronomy. In addition, *Maraston* collaborated with Blue Donut Studios to develop a mobile app called Cosmic Stroll, which allows people to take a virtual walk in the real universe based on SDSS data.

Our appointment of a **Research Fellow in Data-Intensive Science** has enabled us to apply data-analysis techniques from astronomical research to interdisciplinary projects. Moreover, STFC funding, including an **Impact Accelerator Account (IAA)**, has enabled the development of a range of projects:

- A web-based tools for cardiologists from King's College NHS Foundation Trust
- The MoleGazer project with Oxford University Hospitals NHS Trust, which utilises algorithms used for detecting exploding stars in astronomical image data for the early detection of skin cancer
- An interdisciplinary project combining advanced statistical methods and data analytics and Earth modelling to identify geohazards.

#### 4.3 Engaging with diverse communities and the public through research

Under the leadership of our **Senior Outreach and Public Engagement Fellow**, we were the first English university to implement a physics outreach and public engagement strategy, something that other universities have since adopted. We have carried out repeat interventions with 1,400 school pupils from 'widening participation' schools to increase their interest, enjoyment and participation in physics. In 2016 we hosted the UKSA 'Principia Schools Conference' with astronaut Tim Peake, attended by 500 schoolchildren and 1,500 members of the public. Our free annual Stargazing events have been attended by 9,850 members of the public, engaging a broad spectrum of society with our research to increase their awareness of and interest in science. Our work's innovative nature is evident in our success securing £50k of external funding for public engagement projects through STFC and RAS competitive grant

## Unit-level environment template (REF5b)

schemes during the assessment period. Staff members such as *Gupta*, *Maraston* and *Nichol*, make regular appearances on radio and TV, and we regularly contribute to online platforms such as '*The Conversation*' (REF5a paragraph 28).

#### 4.4 Contribution to sustainability of the discipline and responses to national and international priorities and initiatives

In June 2014, we hosted the **National Astronomy Meeting (NAM)**, attracting over 600 participants. NAM is sponsored and coordinated by the RAS and is the society's primary annual meeting. In addition to scientific talks, we hosted public talks, the STFC 'Seeing the Universe in all its light' interactive exhibition and the STFC Industrial Applications of Astrophysics/Astronomy session. NAM2014 was also accompanied by an extensive schools programme with organised events and activities for different age groups and for teachers.

In December 2019, Portsmouth hosted the **30th Texas Symposium on Relativistic Astrophysics**, welcoming 400 researchers from 40 different countries. We organised a free public event where panel members (including *Nuttall* from the ICG) discussed the discovery of gravitational waves from colliding black holes, and a session on equality and diversity which discussed biases in the academic environment and proposed actions to address them. We achieved a good gender balance in invited plenaries and session chairs (35% of our invited speakers were female, compared with 20% of participants overall).

We responded to the national and international crisis caused by **COVID-19** by employing our expertise in image- and data-analysis techniques. In partnership with Portsmouth Hospitals University NHS Trust, we led interdisciplinary projects using satellite imaging to analyse social distancing from satellite data and the spread of droplets in clinical environments.

#### 4.5 Indicators of wider influence on, contribution to and recognition by the research base

##### 4.5.1 Research councils

We provided three sub-panel chairs of the **STFC Astronomy Grants Panel** during this REF period, for **Observational Astronomy** (*Percival*, 2014-15) and **Theoretical Astronomy** (*Wands*, 2015-16, and *Crittenden*, 2018-20). In addition, *Nichol* was a member of the **STFC Science Board** (2013-2016) and **Balance of Programmes exercise** (2017), *Wands* was a member of the **STFC Astronomy Evaluation Panel** (2019), and *Nuttall* is a member of the **UKSA SPAC Affordability Options Review committee**. *Bacon* was a member of the **UKRI Future Leader Fellowships panel** (2019).

*Koyama* was a member of the Research Council of Norway Physics grant panel (2018-2019). *Maraston* is a member of the Caroline Herschel Prize Lectureship panel (since 2018) and was a member of the Hubble Space Telescope Panel Review (2015 and 2016), Italian National Institute of Astrophysics fellowship award panel (2016) and the Hubble Fellowship panel (2018). *Nuttall* was a member of the AAUW international fellowship selection panel (2020), and *Whalen* was a member of the US Department of Energy INCITE program award panel (2017-2019).

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**4.5.2 Learned societies**

*Maraston* is a member of the RAS Award Committee (2015), *Bruni* is a member of the Institute of Physics Gravitational Physics Group committee (since 2017), and *Wands* is a founding board member of the European Physical Society Gravitational Physics Division (since 2017).

**4.5.3 Editorial boards**

Our researchers have served as editorial and advisory board members for several international journals including **Monthly Notices of the RAS** (*Maraston* since 2018), **Classical and Quantum Gravity** (*Wands* 2011-2016, *Koyama* since 2013), and **Europhysics Letters** (*Wands* 2011-2016). *Maartens* was Editor-in-Chief of the journal **General Relativity and Gravitation** (2015-19), published by Springer under the auspices of the International Society of General Relativity and Gravitation. Others have been guest editors for international journals including **Applied Sciences** (*Tamma* 2019) and **Philosophical Transactions of the Royal Society A** (*Goussev* 2016).

**4.5.4 Awards**

The quality of our research is demonstrated by the awards and fellowships won by Portsmouth researchers during this REF period. *Maraston* was awarded the **Eddington Medal for Astronomy** (2018) and *Collett* won the **Winton Award for Astronomy** (2020) from the RAS. *Masters* won the **Women of the Future Award** in Science (2014) and *Maartens* was elected a **Fellow of the International Society for General Relativity & Gravitation** (2019). *Harry*, *Nuttall* and *Lundgren* shared in a number of prizes awarded to the LIGO Scientific Collaboration: the **Gruber Cosmology Prize** (2016), the **Special Breakthrough Prize in Fundamental Physics** (2016) and the **Princess of Asturias Award for Technical and Scientific Research** (2017). In addition, *Pettinari* was awarded the 2014 **RAS Michael Penston award** for the best doctoral thesis in astronomy.

**4.5.5 Other contributions to the international research base**

*Maartens* is an SKA research professor at the University of the Western Cape, *Maraston* was visiting professor at the University of Vienna in 2016, and *Whalen* held an Ida Pfeiffer visiting professorship at the University of Vienna in 2019. *Collett* was awarded a distinguished visitorship at Swinburne and *Wands* is a supervisor for the international PhD programme PPGCosmo run by the Universidade Federal do Espirito Santo in Brazil.

**4.5.6 Invited talks**

Between 2014 and 2020, Portsmouth researchers gave **192 invited conference talks**, **32 invited lectures** at graduate schools, **204 invited seminars** and **114 public talks**. Highlights include: *Bacon*'s invited plenary talk at 'Fundamental Physics with the Square Kilometre Array'; *Canning*'s invited talk at MIT's 'Rising Stars in Physics'; *Harry*'s invited talk at the 5th IUPAP Nuclear Science Symposium; *Koyama*'s invited lectures at the ICTP 'Summer School on Cosmology', Trieste; *Maartens*' invited plenary talk at the 29th Texas Symposium on Relativistic

**Unit-level environment template (REF5b)**

Astrophysics in Cape Town; and *Nuttall's* invited talk at the International Astronomical Union Symposium 338 in Baton Rouge.