

Institution: University of Central Lancashire
Unit of Assessment: UOA9
1. Unit context and structure, research and impact strategy

UoA9 research at the University of Central Lancashire (UCLan) is carried out within the Jeremiah Horrocks Institute (JHI) for Mathematics, Physics and Astronomy (www.star.uclan.ac.uk). As one of the University's three Research Institutes, the JHI is centrally recognised and strategically supported as a centre of excellence. The JHI is one of UCLan's longest-standing research units and it has made a Physics submission to every research assessment exercise since 1992. During the REF2021 period, JHI scientists significantly increased research income, built strong international links and led high-profile projects. Our Institute has a long history of exceptional commitment to external engagement with the local, national and international community via its strategic outreach programmes.

Unit structure

JHI category A staff submitted to UoA9 are broadly grouped into two main specialisms: Astrophysics and Condensed Matter Physics. The former continues building upon long-established research expertise and it has had roughly constant academic staff numbers since REF2014. Complementary to this, the latter has introduced new research strands and increased the number of category A submitted staff since the last REF exercise. The JHI is part of the recently formed School of Natural Sciences; this follows on from the School of Physical Sciences and Computing. Both Schools were/are headed by a JHI staff member (Ward-Thompson).

Astrophysics

Stellar Physics, Solar Physics and Galaxies Astrophysics are the main groupings within Astrophysics. In line with our REF2014 strategic vision to develop areas of strength, the University committed considerable investment to this area, including contributing to funding the James Clerk Maxwell Telescope (JCMT). The JCMT is one of eight telescopes that form the Event Horizon Telescope (EHT) that recently imaged a black hole for the first time. Ward-Thompson's expertise in submm polarimetry meant that he was invited to become a member of the EHT Consortium (making UCLan one of only three UK member Universities). This EHT research carried out during the REF2021 period, won the 2021 Royal Astronomical Society (RAS) Group Award.

UCLan provided funding for mission critical software for the 2018 second flight of NASA's sub-orbital rocket mission High Resolution Coronal Imager (Hi-C2.1). This mission captured EUV images of the corona at unprecedented spatial and temporal resolution. It has funded a similar software contribution for the 2021 NASA sub-orbital rocket instrument, the Marshall Grazing X-ray Spectrometer (MaGIXS). UCLan has also continuously supported membership of the consortium of the Southern African Large Telescope (SALT) since its foundation in 2001.

Condensed Matter Physics

This area has been supported strongly since the last REF, with the appointment of four new Lecturers (Syres, Gamza, Freeman and Lepadatu), widening the scope of our condensed matter research and funding the development of new laboratories. All four staff have been promoted to Senior Lecturers. New equipment purchases include a Magneto-Optical Kerr Effect thin film magnetometer and a state-of-the-art controller for an existing Scanning Tunnelling Microscope (STM). The University has also funded a new Transverse Susceptibility Magnetometer for the measurement of magnetic nanoparticles. These developments are in line with the REF2014 strategic objective of significantly growing experimental physics research.

Category A submitted staff by Research Group

Stellar Astrophysics (3.6 FTEs): *Professor:* Derek Ward-Thompson; *Reader:* Dimitris Stamatellos, *Senior Lecturers:* Jason Kirk, Joanne Pledger.

Unit-level environment template (REF5b)

Solar Physics (3.8 FTEs): *Professors:* Silvia Dalla, Robert Walsh; *Reader:* Daniel Brown. *Principal Lecturer:* Danielle Bewsher.

Galaxies Astrophysics (5.9 FTEs): *Professors:* Victor Debattista, Cristina Popescu, *Readers:*, Roger Clowes, Anne Sansom; *Lecturers:* Megan Argo, Mark Norris

Condensed Matter Physics (6 FTEs): *Senior Lecturers:* Paul Freeman, Monika Gamza, Serban Lepadatu, Tim Mercer, Joe Smerdon, Karen Syres.

At census date the total number of UoA9 JHI academic staff members was 25. Therefore, by headcount, the percentage of Category A submitted staff is 80% (20 academic staff, corresponding to 19.3 FTE).

Equality and Diversity

Our staff profile demonstrates our strong commitment to ensuring equality of opportunity within our discipline. Of the above Category A submitted staff, the proportion of females overall is 40% (8/20), with the following distribution for the various career stages: Professors 40%, Readers/Principal Lecturers 40%, Senior Lecturers 38%, Lecturers 50%. The percentage of women working in our Unit is significantly higher than the typical numbers for UK Physics and Astronomy departments (with the overall percentage of females in Physics and Astronomy departments for the sector being only 19%, based on 2018/19 data). Our proportion of females within category A submitted staff has increased from 29% in REF2014 to 40% in REF2021. Approximately 30% of the submitted staff are non-British.

Sustainability

Within Astrophysics, following the retirement of Kurtz in 2020, Holdsworth's appointment was made permanent to ensure sustainability in the area of Asteroseismology and Extrasolar planets. Within the REF2021 period Dalla was promoted to Professor in the Solar Physics area and so were Debattista and Popescu within Galaxies Astrophysics. Kirk was appointed as Senior Lecturer, working in the area of star formation, which has grown in size since REF2014. The same group saw the permanent appointment of Stamatellos at the end of a UCLan-funded Guild Fellowship. Two new Galaxies Astrophysics staff members were appointed (Norris and Argo).

Within Condensed Matter Physics the four new staff employed during the REF2021 period successfully developed their own research groups and were promoted to Senior Lecturer. Smerdon, appointed to a UCLan-funded Guild Fellowship during the REF2014 period, had his position made permanent and progressed to become Deputy Head of School of Natural Sciences (responsible for Business Engagement and Partnerships).

Achievement of strategic aims from REF2014

The JHI's research strategy during the REF2021 period allowed it to increase the level of external research funding per FTE per year (including REF4a income and UKRI in-kind) by 35% (Section 3, Figure 2) and increase the number of PhD student completions per FTE per year by 18% (Section 2, Figure 1).

Key achievements since REF2014 include JHI staff's scientific leadership in the following areas:

- Development of world-leading simulations of planet formation that incorporate effects of radiative transfer, including radiating feedback of planets into the disk's environment;
- The largest scale high resolution polarisation survey of star forming regions ever undertaken;
- Membership of the Event Horizon Telescope consortium that took the first ever picture of a black hole;
- Pioneering development of models for the Milky Way, including predictions for the large-scale distribution of stars, dust, radiation fields and gamma-ray emission;
- Characterisation of the fine structure of solar coronal loops through high resolution observations with Hi-C;

Unit-level environment template (REF5b)

- Development of new methodologies for simulating solar energetic particle propagation, including the effects of drifts and magnetic turbulence;
- Construction and measurement of a molecular rectifier at the atomic scale, with a rectification ratio orders of magnitude greater than that measured for any comparable system anywhere in the world;
- Development of novel solid-state materials with unconventional superconducting and magnetic behaviour, contributing to our fundamental understanding of mechanisms underlying magnetism and the superconductivity of solids.

Future research strategy

JHI's future strategy is to grow all its main research areas further in targeted ways while continuing to deliver internationally excellent research. The key research questions that will be addressed within the next REF period are as follows.

1) *How do stars and planets form?* Specific activities to address this broad question will include:

- Analysing the initial stages of star formation through JCMT observations;
- Predicting chemical composition of gas giant exoplanets to be compared with JWST observations;
- Establishing the initial conditions for star formation and the role of magnetic fields in collapsing molecular clouds;
- Distinguishing between planet formation mechanisms by deriving the chemical composition of planets formed by disk instabilities;
- Utilising TESS and PLATO data for exoplanet discoveries and characterisation, plus astero-seismological insight into the evolution of stellar interiors.

2) *What are the key processes in the formation of galaxies of different types?* Activities will include:

- Studying the mechanisms through which the bulge of the Milky Way was formed, using simulations and data from Gaia and LSST Vera Rubin;
- Understanding the connection between the bulge and the thick disk and how the latter achieved its properties;
- Obtaining self-consistency in galaxy modelling by incorporating physical processes such as dust physics and cosmic ray propagation in galaxy formation;
- Linking local and global processes in galaxies through radiative transfer, by incorporating the role of pressure-supported diffuse clouds in modelling star formation in galaxies.

3) *How do solar active regions evolve and what is their influence on the Earth's environment?* Activities will include:

- Analysing high resolution observations of the solar atmosphere combined with MHD modelling;
- Understanding the role of perpendicular transport in the propagation of Solar Energetic Particles;
- Developing models that predict solar particle radiation risk for Space Weather applications.

4) *How can we make the functional materials of tomorrow?* Activities will include:

- Developing self-assembled atomically precise nanomaterials for energy and digital electronics applications;
- Studying the fundamental behaviour of interfaces in materials for energy;

Unit-level environment template (REF5b)

- Investigating novel magnetization structures for advanced information storage and processing in spintronics devices;
- Using fundamental research into the emergent collective phenomena of quantum magnets and strongly correlated electron systems.

To achieve our plans, we will continue to invest in staff, infrastructure, equipment, PhD support, and international partnerships (see also Section 3). Staff will be actively supported for promotion to more senior academic roles, through mentorship and other opportunities for development.

Involvement of Stellar Astrophysics staff members in the exoplanet discovery and characterization missions TESS and PLATO will allow answering question 1), together with the strong commitment to JCMT (see Section 3).

To answer question 2), the JHI's Galaxies Astrophysics group will use models and simulations to develop new hypotheses that will be tested with data from ALMA, HESS, FERMI, CTA, Gaia, LSST Vera Rubin and EUCLID. The last will be used to test cosmological evolution of galaxies. Advanced modelling will use the local UCLan HPC facilities and the national DiRAC facilities.

In Solar Physics, answering question 3) will revolve around exploitation of new unique data taken by ESA's Solar Orbiter and NASA's Parker Solar Probe close to the Sun, to answer fundamental questions on coronal structures and solar eruptions. Walsh is co-investigator on the Solar Orbiter magnetometer instrument. Continued collaboration with NASA Marshall Space Flight Centre will include the simultaneous launch of two sub-orbital sounding rockets during a solar flare to image it with unprecedented resolution.

In the area of Condensed Matter Physics, to enable answering question 4), UCLan will expand its Atomic-Resolution Microscopy Facilities, building on the recent acquisition of a low-temperature Scanning Tunnelling Microscope (STM, currently being commissioned). The total investment in the STM lab is £105k.

JHI staff will use international synchrotron facilities to answer questions about the fundamental behaviour at the interfaces of photovoltaics, molecular electronics and gas capture materials, and will look for new host compounds for spin liquid states among frustrated magnets on honeycomb lattices.

Impact strategy

Within the JHI, a strong commitment to impact has been sustained over many years and is part of the ethos within the research unit. At present, the two main areas in which impacts are being developed are Space Weather and public engagement with science. Activities were enabled via investment in sustained, targeted relationships, as well as strategic use of staff time and resources, with support from UKRI and charitable funding.

Impact in Space Weather is taking place via links with the UK Met Office who are using a JHI-developed solar radiation forecasting model, SPARX, within their Met Office Space Weather Operations Centre (MOSWOC). MOSWOC provides 365/24/7 Space Weather monitoring and forecasting to Government and a variety of commercial operators, to mitigate risk. UCLan granted a licence to run the SPARX model to the Met Office. Within JHI, the collaboration is being supported by funding staff time and travel to interact with Met Office forecasters on improvement and evaluation of the model. This effort will continue over the next REF period, with the aim of developing a SPARX impact case for the next REF. New funding for SPARX improvements at UCLan was obtained recently via a 2.5-year NERC grant through the SWIMMR (Space Weather Instrumentation, Measurement, Modelling and Risk) initiative, a four-year Strategic Priorities Fund programme to improve UK capabilities for space weather monitoring and prediction, running through to March 2023.

The Unit is committed to enhancing public engagement (PE) with, and benefit from, our scientific research. The vast majority of JHI members, from postgraduate students to senior academic staff, are intensively involved in outreach projects each year. This work is enabled through supporting staff time, training of PhD students, and making available UCLan facilities, such as Alston Observatory and the UCLan-Royal Institution Young Scientist Centre. These facilities are continuously being improved by UCLan through injection of funding, e.g. to purchase or upgrade telescopes.

Unit-level environment template (REF5b)

The impact case studies for REF2021 have been selected as exemplars within a much larger pool of ongoing projects. The JHI's impact approach had three complementary strands:

- a) Broaden regional engagement activities with a focus on low science capital audiences;
- b) Deepen engagement collaborations with local partners;
- c) Explore Astronomy, Astrophysics and the Arts - examining differing artistic approaches to promote an enhanced understanding of space science and astrophysics.

The JHI pursues partnerships, external collaborations and funding where possible to deliver on the above. We made significant progress on each PE impact strand, including securing approximately £380K funding from a range of external sources (STFC, Arts Council England, RAS and International Astronomical Union (IAU) and others) as outlined in the following-

a) Regional low science capital engagement: With 18% of Preston's population living in local authority areas among the 10% most disadvantaged in the country, the JHI sought to engage extensively with those low science capital groupings. Through a growing regular JHI lecture series, observatory evenings, our schools' outreach programme and significant commitment to UCLan's annual Lancashire Science Festival, JHI researchers engaged with tens of thousands of individuals across over 500 events during the REF2021 period.

Alongside this, Walsh was awarded an STFC Leadership Fellowship in Public Engagement to work with Blackpool schools over a three-year period with multiple interventions.

b) Further local partnership development: Over the REF2021 period, JHI involvement with the Preston and District Astronomical Society (PADAS) progressed significantly, through the University-owned Moor Park Observatory, restored with funding from the Heritage Lottery Fund for use as a regular venue for PADAS meetings and joint outreach events. In the last four years, PADAS membership numbers have tripled.

We worked with the Harris Museum and Art Gallery, Preston, to develop the "*Museum of the Moon*" exhibition for the 50th anniversary of the Apollo landings. JHI staff worked closely with museum staff, lent historical documents to create an associated exhibition and gave over twenty public talks, attended by more than 400 people. The exhibition led to unprecedented interest with over 50,000 visitors over the course of the month-long installation.

c) JHI outreach and the arts: A 2016 STFC-funded pilot programme at the Beacon Museum, Whitehaven, explored creating a new large-scale science/art installation based on NASA Solar Dynamics Observatory data. Three externally funded projects followed-

- Walsh collaborated with artist Alex Rinsler to create the touring art installation SUN. After premiering at Lightpool, Blackpool in October 2019 and LightUpLancaster Festival in November 2019, SUN is now one of two STFC national strategic engagement projects.
- Pledger and dancer Lucy Starkey developed "Into Our Skies" - an online dance workshop targeted at primary school pupils.
- Argo collaborated with storyteller Cassandra Wye to deliver "We share the same moon" as part of IAU100.

The JHI will build upon these PE efforts over the coming REF period, continually examining ways of strengthening the effectiveness of its engagement programmes. Due to the Covid-19 pandemic, a considerable number of impact activities were adversely affected; school engagement stopped, all lectures and observatory events cancelled. All planned SUN installations for 2020 were halted although the dance workshops did move online. These activities will need to be re-energised when allowed. With existing educational, social and economic inequalities exacerbated due to pandemic-related loss of learning, engaging with low science capital audiences will be even more vital. In addition, finding new and innovative ways of reaching audiences such as via artistic approaches to astronomy engagement will be critical. This is now an area of expertise for JHI researchers who can see further opportunities to undertake new collaborations in a range of cultural settings.

Unit-level environment template (REF5b)

Open research

UCLan's open research policies have been consistently applied within UoA9. All research outputs are routinely made available via UCLan's Central Lancashire Online Knowledge (Clok) repository. In the Astrophysics area, all JHI staff members use the arXiv Astro-ph archive to make their work publicly available from the time of submission, as is practice within the field. Funding from UCLan and the Research Councils was used to make the published version of many articles openly accessible via the gold route. The full set of UoA9 outputs submitted to REF2021 is open access compliant.

As an example of open research practice in the area of Condensed Matter Physics, a magnetism computational software package developed by Lepadatu has been made open source and freely available from 2019 (github.com/SerbanL/Boris2). This software includes a substantial user manual to help take-up by the wider research community. Since the software is open source, and includes numerous testing routines and documents, the community is able to verify the validity and accuracy of physical models implemented. This software has been downloaded by over 400 unique users in 2020, and a support forum has been established, showing increased user activity: <https://groups.google.com/g/boris-computational-spintronics>.

Interdisciplinary research

Staff members in the Condensed Matter Group are carrying out interdisciplinary research at the interfaces with Biology, Chemistry and Engineering, with support from the University. As an example, Syres was supported to carry out experiments at the BESSY II synchrotron in Berlin (through travel funding and leave from teaching duties) to work on a project on peptide adsorption on metal oxide surfaces to investigate the biomaterial/biological interface with synchrotron radiation.

Syres is part of an interdisciplinary collaboration involving the Department of Machine Design at KTH Royal Institute of Technology in Stockholm, the UCLan School of Engineering and JHI. The project will develop a novel on-line method of identifying and monitoring lubricant degradation, for prevention of machine failure. It has support from Waters PLC who are providing state-of-the-art mass spectrometers to detect degradation products. It benefits from collaboration with the European Space Tribology Laboratory (operated by ESR technology) who are conducting a spiral orbit tribometer investigation into our ionic liquid lubricants.

Interdisciplinary research involving the UCLan Nano-Biomaterials group (within Chemistry) and JHI staff working on magnetic materials is ongoing. Magnetic nanoparticles are important for biomedical applications in drug-loading and delivery, hyperthermia (heating effect under an alternating magnetic field) and as a contrast agent in MRI scans. Synthesis, surface functionalisation and characterisation of the nanoparticles take place within Chemistry while JHI staff work on characterising and investigating the magnetic properties and application to their intended use. A new collaboration started recently between the JHI magnetism group and the Chemistry-based bio-sensors group.

As an example of policies that enabled interdisciplinary research, Gamza was awarded £85k via the UCLan Research Equipment Fund to purchase a high-vacuum arc-melter with casting option that allowed her to produce and cast rods of alloys needed for engineering projects led by Prof Rivera, LPW / Royal Academy of Engineering Research Chair from Lancaster University, for tailoring phase stability in commercial Ti alloys.

Research integrity

UCLan is a member of the UK Research Integrity Office and signatory to the UK Concordat to Support Research Integrity. UCLan is at the forefront of the promotion of the attainment of high ethical standards as per the Global Code of Conduct for Research in Resource-Poor Settings, with UCLan being the first university in Europe to sign up to this. Training in research integrity is mandatory for all researchers and a robust system of governance and oversight of ethics and integrity is in place through the School and Faculty committees for Ethics and Integrity, supported by a programme of dissemination of good practice across the UCLan academic body. The JHI, as a traditional research institute, promotes research integrity via positive scientific interaction among its members and by maintaining communications and currency with scientific progress, for example through seminars, participation in conferences and external collaborations.

2. People

Staffing strategy and staff development

The JHI strives to provide an inclusive, collegial and stimulating working environment for all its members. Newly hired staff are provided with a mentor to help them settle into their job and the new environment. A formal structure for discussion and advice for all academic staff and postdocs is provided by the appraisal system, consisting of biannual appraisals. Within the Institute appraisals are carried out by the five professors. All appraisers underwent training for the role, including unconscious bias training. Interaction among all JHI members including post-graduate students is promoted via the weekly coffee and doughnuts meetings and seminars, followed by informal sessions with opportunity to talk with colleagues and the seminar speaker.

In addition to the centrally provided Academic Researcher Induction programme, at University level a full programme of staff development is available for all career stages, including for example postgraduate supervision training, training on writing grant proposals and development of research management skills. ECRs in particular are actively encouraged to make use of these opportunities to gain independent research funding.

Since the last REF, a significant number of promotions have occurred with three promotions to Professor (Dalla, Debattista and Popescu), three to Reader (Brown, Sansom and Stamatellos) and seven to Senior Lecturer (Freeman, Gamza, Kirk, Lepadatu, Pledger, Smerdon and Syres). In particular, female members of staff have been actively encouraged to apply for promotion, via the appraisal system. Two female academic staff achieved promotion to professor during the REF2021 period. They are the first since the founding of the research unit. Of the promotions to Reader and Senior Lecturer combined, 40% were of female staff members.

Stamatellos and Smerdon completed their UCLan Guild Fellowships during the 2015/16 academic year and their positions have been converted to permanent academic staff posts. They have since progressed to Reader and Deputy Head of School, respectively.

During the REF2021 period, funding for sabbaticals was provided by UCLan for four JHI staff members (Debattista, Brown, Bewsher and Mercer), for a duration of 6 months each. In addition to his sabbatical, Debattista benefitted from 6 months' research leave that allowed him to carry out research at the University of Zurich, funded by the latter. Popescu had research leave for a total of five months to allow her to work at the Max Planck Institute for Astronomy in Heidelberg, funded by MPIA.

Regarding JHI staff leavers during the REF period, Prof Andrei Zvelindovsky went on to become founding Head of the School of Mathematics and Physics at the University of Lincoln and Prof Brad Gibson left to form and lead the new E.A. Milne Centre for Astrophysics at the University of Hull. Prof Don Kurtz retired in early 2020: he maintains a connection with UCLan as Emeritus Professor and he is also Extraordinary Professor at North-West University in South Africa. Dr Stewart Eyres progressed to become Associate Dean of Computing, Engineering & Science at the University of South Wales.

Postgraduate students

The JHI currently hosts 19 PhD and 14 MSc by Research students. Funding for PhD studentships is provided via Doctoral Training Studentship grants from STFC in the Astrophysics area, complemented by University funding and by the Moses Holden Studentship scheme for both Condensed Matter Physics and Astrophysics. Progression of all postgraduate research (PGR) students is monitored via an annual review system managed by the University's Graduate Research School and also specifically for PhD students through the MPhil/PhD transfer process.

PGR students are supported via a programme of physics/astrophysics-specific PGR Lectures given by JHI academic staff, consisting of a total of 40 lectures per year. A comprehensive research skills training programme is provided centrally by the University. The latter includes extensive 2-week training for PGR students at the start of their study and additional events and online training as they progress. New PhD supervisors benefit from an induction programme provided at University level.

Unit-level environment template (REF5b)

Postgraduates are required to attend weekly research seminars, part of the JHI Seminar series, given by external speakers, and they have the opportunity to interact with speakers during lunch/dinner and during an informal chat session immediately after the seminar. Each year PGR students have to give a presentation about their research, attended by JHI members. Further support and scientific interaction are provided within research groups, via group meetings and journal clubs. Students actively participate in the Annual UCLan PGR Day and the university's Three Minute Thesis Competition, which feeds into the Vitae national competition.

Funding is provided for student attendance to formative events such as Royal Astronomical Society (RAS) and Institute of Physics (IOP) meetings and international conferences; in many cases targeted internal JHI funding supports the students well beyond the travel funding provided within their studentship. PGR students are actively encouraged to apply for opportunities to broaden their experience. For example, during his PhD Tom Davison won both an Isaac Newton Group Studentship (letting him spend a year working in La Palma) and an ESO studentship (to spend a year at ESO in Garching).

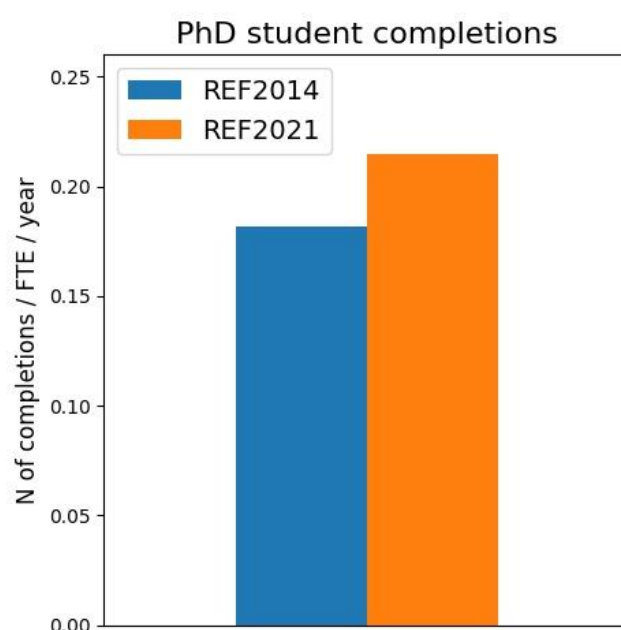


Figure 1 - Comparison between PhD completions in REF2014 and REF2021

[Values plotted are PhD completion numbers per submitted staff FTE number per year. Actual completion numbers are 19 for REF2014 and 29 for REF2021.]

We ensure that PGRs are well integrated within the research Institute and feel part of its fabric. Our varied social events contribute to a vibrant intellectual atmosphere in the JHI community. At our weekly coffee and doughnuts meetings everyone, from the Head of School to the newest PGR student, takes turns to make the coffee and bring the doughnuts. We strongly encourage our PGRs to participate in outreach activities, such as observing nights at Alston Observatory and the annual Lancashire Science Festival.

Compared to REF2014, during the REF2021 period there has been an 18% increase in the number of PhD student completions per submitted staff FTE per year (Figure 1). This increase took place despite a challenging environment for both Research Council support for studentships and PGR funding generally.

Equality and Diversity

As detailed in Section 1, the JHI has a 40% representation of female staff among Category A submitted staff. The same percentage (40% female) is reflected in non-submitted staff members, demonstrating that there is no over-representation in staff who do not have significant responsibility for research. The representation of female staff at all career stages is a result of Equality and

Unit-level environment template (REF5b)

Diversity (E&D) policies within the University and the JHI, including appraisal, sabbaticals, mentoring and training. There are currently no Black, Asian or ethnic minority staff members among Category A submitted staff, and the same is true for JHI UoA9 staff members not submitted to REF2021. However, we have plans to increase BAME representation within JHI academic staff, by supporting our current BAME PGR students in their career development as well as continuing to pay close attention to the University's Equality, Diversity and Inclusion policy when recruiting new staff.

The proportion of female staff within the JHI has been historically high over the last 25 years, as a result of attention to E&D by the JHI Directors within the staff recruitment process. Of the six new appointments within the REF2021 period, 50% have been female (Gamza, Syres and Argo). Recently two females have been promoted to professors (Popescu in 2016 and Dalla in 2017). There has been a constant focus on supporting career progression for female staff members via the appraisal system and the provision of training opportunities. For example, Dalla benefitted from a 10-module programme of Research Leadership development taking place over a whole academic year, funded by the University.

UCLan was awarded the Athena SWAN Bronze award in March 2020. The School of Natural Sciences (of which the JHI is now a part) is working towards its Athena SWAN application which will be finalised and submitted within the next 12 months. This follows an overall University restructure of Schools (the JHI itself was not restructured), which resulted in a different subject composition. The application will be submitted for the specific subjects that are part of the new School grouping. Data on staff have been collected and analysed in preparation for the submission. The School has invested in this effort by dedicating 0.2 FTE of a new senior Principal Lecturer position to focus specifically on E&D.

During the REF2021 period two JHI academic staff members (Bewsher, Pledger) and one PDRA (Konyves) took maternity leave. Two maternity cover posts were funded by UCLan to cover the teaching of the academic staff members while they were on leave. All three staff took advantage of phased return to work with both academic staff members currently working part-time. Alongside this, Bewsher was awarded a research sabbatical following her return to work. Of the three staff members that went on maternity leave, two took advantage of the University-supported UCLan Pre-School Centre upon returning to work.

We know of current and past JHI academic staff, postdocs and students who are part of the LGBT+ community and other protected characteristics groups, including gender-reassigned individuals. They are and always have been fully supported within the Institute and the University, as have all individuals with protected characteristics, for example via networks such as the BAME, LGBT+, Disability and Women's network. UCLan have been awarded the Race Equality Charter and are part of the Stonewall Diversity Champions Programme. The JHI fully implement the University's Equality, Diversity and Inclusion Policy.

3. Income, infrastructure and facilities

External grant income and in-kind income

JHI research income, including external income (REF4a) and UKRI in-kind, increased from £3.5M in REF2014 to £6.1M in REF2021. In units of income per FTE per year this represents a 34% increase compared to REF2014. This is well above the rate of inflation: after correcting for inflation, the increase in real terms is between 18 and 21%, depending on the methodology used for the correction. Given that all Research Councils have been operating on a 'flat cash' basis over most of this REF period, a 34% increase (~20% after correcting for inflation) is a very significant result.

Figure 2 compares REF2014 and REF2021 income, including external REF4a income, UKRI in-kind and in-kind income from non-UKRI sources, as estimated in Tables 1 and 2 below. Non-UKRI in-kind income also had a very substantial increase since REF2014.

When non-UKRI in-kind income is included in the total the percentage increase in income per FTE per year is 56% compared to REF2014 figures (see Total in Figure 2).

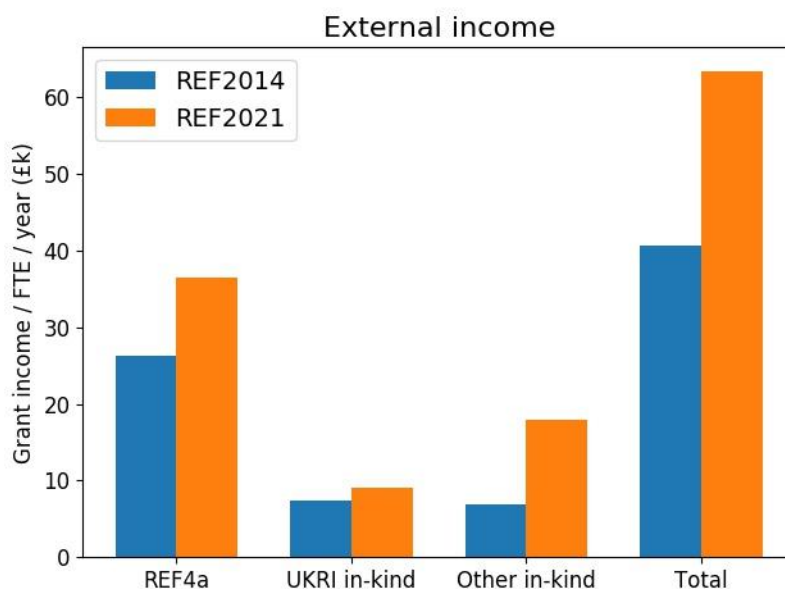


Figure 2 – Comparison between external income in REF2014 and REF2021

[Values plotted are total income per year per category A submitted FTE number. Included are REF4a income and in-kind income from UKRI sources. For REF2014 these totalled £3,522k (of which £776k UKRI in-kind) and for REF2021 £6,111k (of which £1,218 UKRI in-kind). Also given in the histogram under 'Other in-kind' is income from non-UKRI sources as per the estimates of Tables 1 and 2.]

The increase in research funding shown in Figure 2 was achieved against an extremely challenging funding environment, for example 'flat cash' in the STFC grants line. In addition to 'traditional' funding from STFC and the EU, during the REF2021 period research in the JHI also benefitted from the award of two Leverhulme Trust Research Project grants, and other income.

JHI staff were successful in obtaining income-in-kind through competitive peer-reviewed applications. This was mostly in the area of Astrophysics through winning observing time on international telescope facilities and in the Condensed Matter Physics area through award of time on national and international facilities (e.g. 'beam' time). Income-in-kind from UKRI facilities included time on Diamond Light Source, ISIS Neutron facility and the neutron beam at Institut Laue-Langevin, competitively awarded to Condensed Matter Physics staff (Syres and Freeman), as well as telescope time (JCMT, ESO, Isaac Newton Telescope, e-Merlin) and time on computational facilities (Dirac), to Astrophysics staff (Pledger, Stamatellos, Argo, Debattista, Ward-Thompson and Laitinen, a PDRA).

Tables 1 and 2 detail the income from non-UKRI sources, awarded by panels of international peers/experts following competitive review. Income is estimated by using published yearly operational costs of each facility, keeping into account the time awarded via competitive applications. Tables 1 and 2 only list awarded time for proposals with JHI members as PI, obtained since they joined UCLan. Further in-kind income was obtained on projects as co-I and as PI within the REF2021 period before joining UCLan, but they are not listed here.

The total value of UKRI and non-UKRI income-in-kind for REF2021 amounts to £1,218k + £2,421k = £3,639k, a substantial increase compared to REF2014 (£1,500k). In part this is the result of the expansion of the JHI's Condensed Matter research group which took place during the REF2021 period, allowing new income from Physics facilities to be added to the JHI's traditional income from telescope time, but mostly this was due to all research-active staff submitting competitive bids.

Table 1 – Non-UKRI Income-In-Kind: Time won on international telescope

Telescope	Location	PI	Time	Estimated Value (£k)
JCMT	Hawaii	Ward-Thompson (PI of BISTRO project) ^a	67 nights	670
Large Binocular Telescope, MODS	Arizona	Norris	26 hrs	156
Kepler + TESS	Space	Holdsworth (PDRA), with co-I Kurtz	160 + 27 days	355
SAAO 1.0m + 1.9 m	South Africa	Holdsworth (PDRA), with co-I Kurtz	155 + 28 nights	348
ALMA	Chile	Sansom	3 hours	26
IRAM 30m	Spain	Glass (PhD student), with co-I Sansom	94 hours	64
Total value of non-UKRI telescope time				1,619

[To estimate the value of income-in-kind for non-UKRI facilities we divided the total yearly operations budget by an estimate of the total number of observing hours (300 nights/year), then multiplied by the time awarded. Yearly operation budgets for the majority of telescopes are published online and in a few cases we obtained them by direct contact with telescope staff. All the awards listed above were obtained via international competitive peer-reviewed application to Telescope Allocation Committees and the UCLan staff member was PI on the proposal. For Kepler and TESS time, particular targets were approved to be observed within a specific mode, but this was together with targets for a number of other proposals. Therefore, we used a small fraction (£2k/day) of the daily operational cost in our estimate. Notes: a) funding received via Cardiff University block grant.]

Table 2 – Non-UKRI Income-In-Kind: Time won on Physics facilities

Facility	Location	PI	Time	Estimated Value (£k)
Institut Laue-Langevin, neutron beam (Swiss-funded) ^b	Switzerland	Freeman	11 days	410
Argonne National Laboratory, Optical UHV VT AFM/STM	USA	Smerdon	56 days	68
ASTRID2	Denmark	Syres	13 days	234
MAXIV, HIPPIE beamline	Sweden	Syres	5 days	90
Total value of non-UKRI Physics Facilities time				802
Total non-UKRI in-kind-income (Table 1 + Table 2)				2,421

[To estimate the value of income in kind for non-UKRI facilities we divided the total yearly operations budget by an estimate of the total running time, then multiplied by the time awarded. Yearly operation budgets for the majority of facilities are published and, in some cases, we contacted facilities staff to obtain the information. All the awards listed above were obtained via international competitive peer-reviewed application and the UCLan staff member was PI on the proposal. Notes: b) Funding (Proposal n. 4-01-1423) was awarded while Freeman worked in Switzerland (hence not included in the UKRI tables) and experiment was carried out while he worked at UCLan; estimate based on cost per instrument day at ILL information provided by UKRI.]

UCLan investment in facilities

UCLan supported membership of the consortium of SALT since its foundation in 2001. This will be consolidated by continuing to invest £25k/year. The University will also continue its current commitment to the JCMT by contributing £25k/year. JCMT is part of the EHT project, awarded the 2020 Breakthrough Prize in Fundamental Physics.

SALT is now in a phase of development of its next generation instrumentation. This will broaden the science capabilities of the telescope through the introduction of a near-infrared spectrograph, a new maximum efficiency spectrograph to enable rapid follow-up of transient events (triggered from e.g. MeerKAT and LSST Vera Rubin), and the upgrading of the current High Resolution Spectrograph to allow SALT to break into the field of exoplanet radial velocity follow-up. All of these projects are possible thanks to funding provided by SALT partners including UCLan and will have direct impacts on the research of the JHI. At JCMT UCLan investment will aid important development of the next generation imaging polarimeter, with mapping speeds 1000 times faster than currently. The new capability will be crucial for future star formation studies led by JHI staff.

Throughout REF2014 and REF2021 the University provided support for its in-house HPC facility, heavily used by JHI Astrophysics numerical modellers (approximately 80% of overall University usage). A review of HPC provision is currently taking place at Faculty level and it is planned that during the next REF period new in-house facilities will be made available, as well as access to external virtual platforms for large scale simulations. The investment will enable further research developments in the areas of galaxy simulations, planet formation and solar physics.

During the REF2021 period UCLan invested £250k to buy and install a new 0.7-metre telescope at the JHI's Alston Observatory in rural Lancashire, which can be used for anything from deep-sky imaging to planet hunting. This facility is being used for staff research projects and for teaching and outreach. The University will invest £50k in a wider field telescope specifically for robotic wide field planet hunting in the next 12 months.

In the area of Condensed Matter Physics, the University will expand its Atomic-Resolution Microscopy Facilities, building on the recent acquisition of a low-temperature Scanning Tunnelling Microscope (STM). This should be commissioned in time for the start of the next REF cycle. The total investment in the STM lab is £105k.

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

Research Collaborations

In the Astrophysics research area, JHI staff are involved in several international research collaborations and teams, often in a leadership position.

Debattista is Group co-Lead for the LSST Vera Rubin Observatory Milky Way Bulge roadmap and a member of the "Milky Way Structure" Science Collaboration of the Vera Rubin Observatory. He is the UK Point of Contact and PI for Vera Rubin Observatory bulge science.

Ward-Thompson is PI of the BISTRO International Consortium (BISTRO is a JCMT-SCUBA-2 polarimeter survey of star formation). He is a member of the Event Horizon Telescope Consortium (EHT) that published the first picture of a black hole, the ESA Herschel Space Telescope SPIRE Consortium, the James Clerk Maxwell Telescope (JCMT) UK Consortium and the Development in Africa with Radio Astronomy (DARA) Consortium funded by the UKRI/STFC Newton Fund.

Popescu and Sansom are members of the Galaxy and Mass Assembly (GAMA) consortium, carrying out a wide field spectroscopic survey of galaxies. Kurtz (now retired) has been a member of the Kepler Asteroseismic Science Consortium Steering Committee (2009-2014). Walsh is Co-I and institutional lead on the sub-orbital sounding rocket programme under PI Winebarger (NASA MSFC) and fellow Co-Is Golub (Harvard Smithsonian CfA), Peter (Max Planck Institute for Solar System Research) and Warren (NRL).

In the Condensed Matter area, national and international research collaborations are being pursued. These include work with Aarhus University in Denmark on ionic liquids on metal oxide surfaces for

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photovoltaic applications, and with Lund University in Sweden on CO₂ capture by super-basic ionic liquid thin films (Syres). Smerdon has ongoing collaboration with the Centre for Nanoscale Materials at Argonne National Laboratory, on molecular electronics. Gamza works with collaborators at the Max Planck Institute for Chemical Physics of Solids in Germany, on the physics and chemistry of novel intermetallic phases, and with researchers at the Cavendish Laboratory, University of Cambridge, on topological systems and materials displaying Fermi surface instabilities.

Conferences

JHI Staff organised an international conference on *Understanding the roles of rotation, pulsation and chemical peculiarities in the upper main sequence* in the Lake District in September 2016 (www.star.uclan.ac.uk/stars2016), which was attended by more than 70 participants from all over the world. Smerdon and Syres organised the first UK Surface Science Day conference, held at UCLan in 2015 and run yearly since then at other UK locations.

Further contributions to conference activities took place via participation in SOCs and organisation of a number of conference sessions. For example, Debattista was Chair of the Science Organizing Committee for the conference “*The Role of Gas in Galaxy Dynamics*”, Valletta, Malta, (2017), and for the workshops “*Nuclear Clusters in Galaxies, and the Role of the Environment*”, Leiden, Netherlands (2014) and “*Thin, Thick and Dark Disks*”, Ascona, Switzerland (2017). A number of staff members organised RAS meetings and NAM Sessions.

A total of 80 invited talks were presented by JHI speakers at international conferences. Some of the highlights are as follows: Debattista was a Keynote Speaker at the conference on “*Deconstructing Galaxies: Structure and Morphology in the Era of Large Surveys*”, held in Santiago, Chile, in November 2013. Popescu was an Invited Speaker and Discussion Leader at the international conference ‘*Dusting the Universe*’ in Tucson, USA in 2019. Dalla was Invited Rapporteur Speaker for Solar and Heliospheric Physics at the 36th *International Cosmic Ray Conference*, Madison, USA, 2019. Ward-Thompson was Invited Speaker at the IAU Symposium 315: ‘*From interstellar clouds to star-forming galaxies: universal processes?*’ (during IAU General Assembly, Hawaii, 2015). Stamatellos was invited to give a Review Talk on “*The theory of the formation of brown dwarfs and low-mass stars*” at the conference “*Star formation from Cores to Clusters*” that took place in ESO, Chile, in March 2017.

Leadership within the Academic Community

JHI staff have taken on positions of responsibility within the scientific community in a number of roles: Popescu is President of the IAU Commission J1 (*The Spectral Energy Distribution of Galaxies*) since 2018, having been Vice-President of this Commission during 2015-2018. Since June 2020 Argo, who is an ECR, has been Vice President of the RAS and she has been RAS Council member since 2017. Kurtz was RAS Vice-President during 2015 – 2017 and served on RAS Council during 2012 – 2014. Popescu is a member of the Steering Committee of the IAU Division J (*Galaxies and Cosmology*). Argo is a member of the Organising Committee of the IAU Commission C2 (*Communicating Astronomy with the Public*) (2015-present).

A JHI academic member of staff (name not disclosed for confidentiality reasons) sits on one of the European Research Council (ERC) grants panels for 2019-2022. Brown was Deputy Chair of STFC's Astronomy Grants Panel during 2013-2015 and in 2020, and a member of STFC's Solar Physics Facilities Review Panel (2017). Ward-Thompson is currently on the STFC Project Peer Review Panel (PPRP) for two years (2020-2022). Dalla is currently on the Solar Missions Post-Launch Support Oversight Committee, reporting to the UK Space Agency (2019-present). Debattista served on the NASA Astrophysics Data Analysis Program grant panel (2015), and the NSF Theoretical and Computational Astrophysics Networks programme panel (2018). Dalla was a member of an international panel carrying out a 5-yearly review of the School of Cosmic Physics, Dublin Institute of Advanced Studies. Gordon Bromage (UCLan Emeritus Professor) was Chair of the 2015 decadal review of Armagh Observatory's research and outreach.

Sansom is a member of the international ALMA review panel (for telescope time applications) since 2019. In 2019 she was deputy-chair of a sub-panel and in 2020 she chaired it. Argo is on the UK Time allocation panel for the Isaac Newton Group of telescopes (2018-present) and she sits on the

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Funding panel of the IAU Office of Astronomy for Development (2015-present). Kurtz was a member of the External Advisory Board of the Hungarian Academy of Sciences (2017-2020). Ward-Thompson was a member of the UK ALMA Oversight Committee (2012-2019).

Walsh was a member and rotating chair of STFC's Innovation Partnership Scheme Assessment Panel (2014-2017) and currently sits on STFC's assessment panel for the Leadership Fellowships in Public Engagement.

Argo is a member of the RAS "A" (Astrophysics) Awards Committee (2018-present) and Ward-Thompson (2011-2015) and Kurtz (2015-2017) have been members of the same panel – the latter chaired it for a year. Dalla has been a Member of RAS "G" (Geophysics) Awards Committee (2013-2015).

Syres is Vice-Chair of the Institute of Physics (IOP) Thin Films and Surfaces Group Committee (since 2017). Mercer sits on the IOP Magnetism Group Committee. Ward-Thompson is an Assessor within the IOP Accreditation Panels. Since January 2020 Syres has been a member of the Daphne Jackson Trust assessment panel, which reviews fellowship applications.

As mentioned in Section 1, UCLan/JHI is a Founder Member of SALT and has supported it continuously since its foundation. Bromage was the UK's only member of SALT's Board of Directors (2012-2015) and Europe's only member of SALT's Finance Committee. He sat on the SALT Finance/Audit Committee continuously during 2013-2021.

Public engagement activities

As outlined in Section 1, our extensive work within public engagement focussed primarily on three strands: (i) engaging low science capital, under-served, non-traditional communities; (ii) further developing collaborations with local partners; and (iii) exploring the interface between astrophysics, art and culture. As indication of the quality of the PE work carried out by the JHI during the assessment period, Walsh was awarded the RAS Annie Maunder Medal for Outreach in January 2021.

Particular highlights include, in addition to those already mentioned in Section 1-

- Significant growth in the number of visitors to Observatory open evenings (tripled during this period), the JHI Public Lectures (four per year) by high profile external speakers and the annual Lancashire Science Festival.
- Continuing schools engagement activity, including funded projects from the Ogden Trust, a dedicated Isaac Physics Fellow mentoring several local schools as well as regular physics masterclasses at Cardinal Newman Sixth Form College.
- JHI hosted INTERACT Symposium in September 2019, a unique event in the physical and life sciences that was developed and delivered alongside STFC, RAS, IOP, SAC and the Ogden Trust.
- Ward-Thompson was President of the UK Society for Popular Astronomy (SPA) during 2012-2014 and Walsh is IAU UK National Outreach Coordinator since 2019.
- For the IAU100 centenary in 2019, Walsh organized a national competition for UK school children to name an exoplanet and its host star. The final names (exoplanet 'Cruinlagh' and its host star 'Gloas') were selected from over 1,000 suggestions, submitted by more than 10,000 young people.
- Walsh co-authored the UCLan multi-disciplinary popular science book "Unmasked: The Science of Superheroes", supported by STFC and the Reading Agency to place two copies in every library across the UK.

International Public Engagement

Prof Don Kurtz (who retired from JHI in 2020, prior to the census date) has been involved in a number of outreach activities promoting astronomy in Africa. These included: lecture courses at the University of Cape Town Astronomy Summer School for the public in 2017 and 2019; popular talk to 300 school children at Hizunan Medehanealem School, Addis Ababa in 2018, with sponsorship from

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the Ethiopian Space Science and Technology Centre; talk to pupils from four schools (80 children) at the Botswana International University for Science and Technology; several public talks and star talks in South Africa. Also, Walsh began a partnership with Kibogora Polytechnic in Rwanda to improve school science teaching using astronomy and he led an outreach activity at the 2017 eclipse in the US. Argo is heavily involved in IAU commission C2, promoting astronomy in developing countries and is on the funding panel of the IAU Office of Astronomy for Development.

Kurtz contributed to the training of postgraduate and advanced undergraduate students in Africa by presenting Introductory Astrophysics, a 10-day all-day lecture course, at the University Eduardo Mondlane in Mozambique, under the auspices of DARA (Development in Africa with Radio Astronomy) in 2019 (a consortium of which the JHI is still part). Ward-Thompson has a DARA-funded PhD student from Zambia. During DARA consortium meetings in South Africa, Kurtz interacted with and advised several of the 80 students from eight African countries. In 2018 Kurtz presented an intensive all-day two-week course in Astrophysics at the Mbarara University of Science and Technology in Uganda, to postgraduate and undergraduate students.