ERC Consolidator Grant 2018
Research proposal [Part B1]
(Part B1 is evaluated both in Step 1 and Step 2, Part B2 is evaluated in Step 2 only)

Quasars in the 4th Dimension

Q4D

Principle Investigator: Nicholas P. Ross
Host Institution: University of Edinburgh
Duration: 60 months

Along with nuclear fusion in stars, accretion onto a central supermassive black hole is the main energy source available to a galaxy. All massive galaxies are thought to have supermassive black holes at their centres, and to have undergone a "quasar phase" in their past, which has led to the hypothesis that energy from the quasar feeds back into the galaxy, becoming a regulating mechanism and shutting down star formation. However, while the fusion processes in stars have been on a solid theoretical footing for over 70 years, current theories of galaxy formation and evolution are still missing a deep understanding of how the energy associated with the supermassive black hole escapes the central engine to impact the host galaxy and the intergalactic medium.

Further issues arise since very recent observations of extreme variability in quasars, where some objects show changes in luminosity and activity *over the course of weeks to years,* have broken standard viscous accretion disk models.

Here we propose to use and combine the data from several next-generation state-of-the art surveys (SDSS-V, DESI, LSST, 4MOST, ESA *Euclid* and JWST) in order to go beyond the state-of-the-art and construct the extragalactic dataset with the crucial time-domain aspect that is necessary to address these current challenges. Our goal is to create and exploit a revolutionary new extragalactic dataset of the variable extragalactic Universe. We will use this as the boundary conditions for a holistic theory of accretion disk physics and quasar feedback in galaxy formation theory. I am also extremely well placed to discover brand new extragalactic variable phenomena. The experience of the PI, along with the strategic data centre aspect of the Royal Observatory at the University of Edinburgh makes my group uniquely positioned to answer this challenge, and provide a fundamental new understanding of quasars and galaxy formation and evolution.

Section a. Extended Synopsis of the scientific proposal (max. 5 pages, references do not count towards the page limits)

Overview and Objectives

Current theories of galaxy formation and evolution strongly suggest that central, supermassive black holes (SMBHs) have a profound effect on the galaxies that they live in (e.g., Kormendy and Ho, 2013). This is not surprising since the potential energy associated with mass accretion onto a supermassive black hole is comparable to that generated via the nuclear fusion in the galaxy's stars (see e.g. Fabian, 2012). Thus when a galaxy goes through a "quasar phase" (where gas is supplied and accreted by the SMBH) there is ample energy to potentially impact the host galaxy and the surrounding intergalactic medium.

However, the critical details of the physical processes involved in how this energy escapes the inner most regions of the galaxy and then interacts with the gas, dust, stars and dark matter, is currently poorly understood. This fact, along with current observational data giving more puzzles than clues is preventing the field from moving forward. Significant further issues arise since startling new observations from my (Nicholas P. Ross; NPR) research team (MacLeod et al., 2016; Ross et al., 2018) show that *quasars vary significantly on timescales of weeks to months*, whereas the accretion disks (that supply 'fuel' for the quasar) should take thousands of years to change their optical emission. This has recently been called the "Quasar Viscosity Crisis" (e.g., Lawrence, 2018). Thus, it is unclear if we have an understanding of a physical phenomena prevalent in many astrophysical systems: the accretion disk.

The field of observational extragalactic astrophysics is poised for a fundamental and rapid change. Starting in late 2019, a fleet of new telescopes, instruments and missions will be commissioned, start data taking, and will leap-frog the quality and quantity of data we have available today. These surveys and missions include: the fifth incarnation of the Sloan Digital Sky Survey (SDSS-V[1]); the Large Synoptic Survey Telescope (LSST[2]); the Dark Energy Spectroscopic Instrument (DESI[3]) survey; the 4-metre Multi-Object Spectroscopic Telescope (4MOST[4]) survey, and the ESA *Euclid* mission[5]. Even more imminent is the launch of the *James Webb Space Telescope* (JWST[6]).

Quasars in the 4th Dimension (Q4D) has two broad and well-posed goals. First, we aim to elucidate in detail **how the energy directly associated with a supermassive black holes impacts the universal galaxy population.** We will gain a deep understanding into the physical mechanisms related to central engine black holes; their accretion disk physics, their dynamics on both human and galactic timescales and the role they might play in forming and regulating the galaxy population. Second, we anticipate **the discovery of brand new extragalactic phenomena.** By tapping into the massive raw discovery space that the new experiments will open up, there is the highly likely outcome of discovering something "brand new" (Ivezic and Tyson, 2008; LSST Science Collaborations et al., 2009), e.g. the EM counterparts to mergers of Binary SMBHs (with their associated gravitational wave chirp and ringdown), objects potentially similar to repeating Fast Radio Bursts (Spitler et al., 2016) or more objects akin to the still unexplained 'SCP 06F6' (Barbary et al., 2009). The Q4D objectives are:

1. Characterize the variable extragalactic universe and quasar population.
2. Establish the energy transport mechanisms associated with the "quasar phase", and explain the relation between accretion rate and black hole mass build-up, with observed light curve and spectral properties.
3. Develop and then link theoretical accretion and galaxy formation models for a fully holistic theory of active galaxies.
4. Discover new extragalactic variable objects.

We will achieve this by leveraging several of the new, large-scale surveys that will all have 'First Light' over the lifetime of the project. These critical observations are made by exploiting the large imaging and spectroscopic

[1] www.sdss.org/future/ [2] lsst.org [3] desi.lbl.gov [4] 4most.eu [5] sci.esa.int/euclid/ [6] jwst.stsci.edu

datasets that will be available from the SDSS-V, DESI, 4MOST, LSST and ESA *Euclid*. **Crucially, although these projects individually will deliver new state-of-the-art datasets, it is my project that will be the first to break down the associated data silos and combine these data in order to go beyond the state-of-the-art.**

1. Current State of the Art.

The current state-of-the-art data samples have either $\approx 10^6$ quasars with one spectral epoch, or only a few objects with repeat photometric data, i.e. light-curve information and the accompanying repeat spectra (see Figure 1). I have been intimately involved in the production of both of these two types of samples (MacLeod et al., 2016; Pâris et al., 2017). My group plans to collate datasets so that the 10^6 sample have *high-fidelity light-curves and ample repeat spectroscopy (necessary for emission/absorption line diagnostics)*, and in doing so will kick start the new field of Variable Extragalactic Astrophysics.

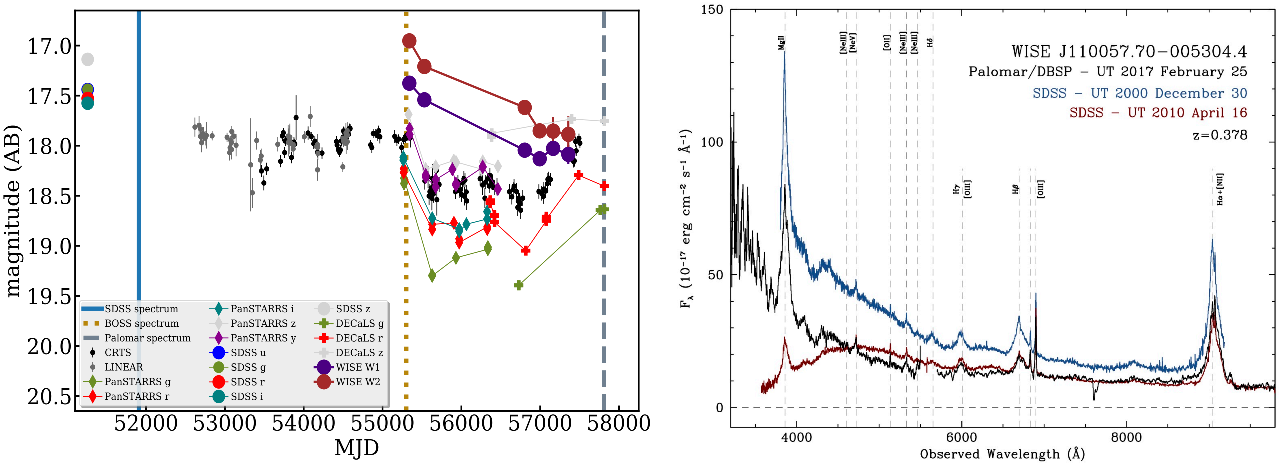

Figure 1: *(Left:)* The optical and infrared light-curve for the redshift $z = 0.378$ quasar J1100-0053 (Ross et al. 2018). Note the fall in the infrared, whereas there is a decrease, but then recovery in the optical. *(Right:)* Three epochs of spectra for J1100-0053. The spectacular downturn in the blue for the 2010 spectrum indicates a dramatic change in the accretion disk.

During its initial phases of operation the Sloan Digital Sky Survey (SDSS) obtained spectra of 1 million galaxies in the local Universe. This dataset has become the *de facto* standard for understanding the present day galaxy population, and sets the boundary conditions for all theoretical comparisons. The paradigm changing success of the SDSS was due to having 1,000,000 objects *with very high signal-to-noise photometry and spectra*, enabling multivariate analysis that is required for galaxy astrophysics investigations. *Q4D will generate the same sample size and revolutionary understanding with a new temporal dimension of the quasar population, as the SDSS had with the low-redshift $z \sim 0.1$ galaxy population.* The ground-breaking aspect of Q4D is that it takes quasar astrophysics into the 2020s, going from single objects samples, to surveys and samples of millions of objects, with massive spectroscopic monitoring giving access to the time-domain and leveraging these very large scale next generation missions, telescopes and their datasets.

The timing for this proposal could not be better. The first of the data "firehoses" turns on in late 2019, with the full datastream from our key sources fully online by mid-2022. As such, we have the time to mature our analysis techniques, and then be in the ideal position to take advantage of the initial data releases of all these new projects. Prompt ERC Consolidator level-support is also imperative since final survey design and optimization trade-off studies are being made e.g. for SDSS-V and LSST over the next ~12-18 months. Having the ability to influence and fully optimise these decisions for our science objectives will be very powerful. The ground breaking nature of the Q4D will attract high quality PDRAs, *who would be guaranteed "First Light" data and science.*

The importance of this branch of astrophysics is already well established in Europe and is a priority for the next two decades.[7],[8] This is demonstrated by noting that one of the two primary mission goals for the ATHENA

[7] ESA Cosmic Visions [8] L-Class Mission Timeline

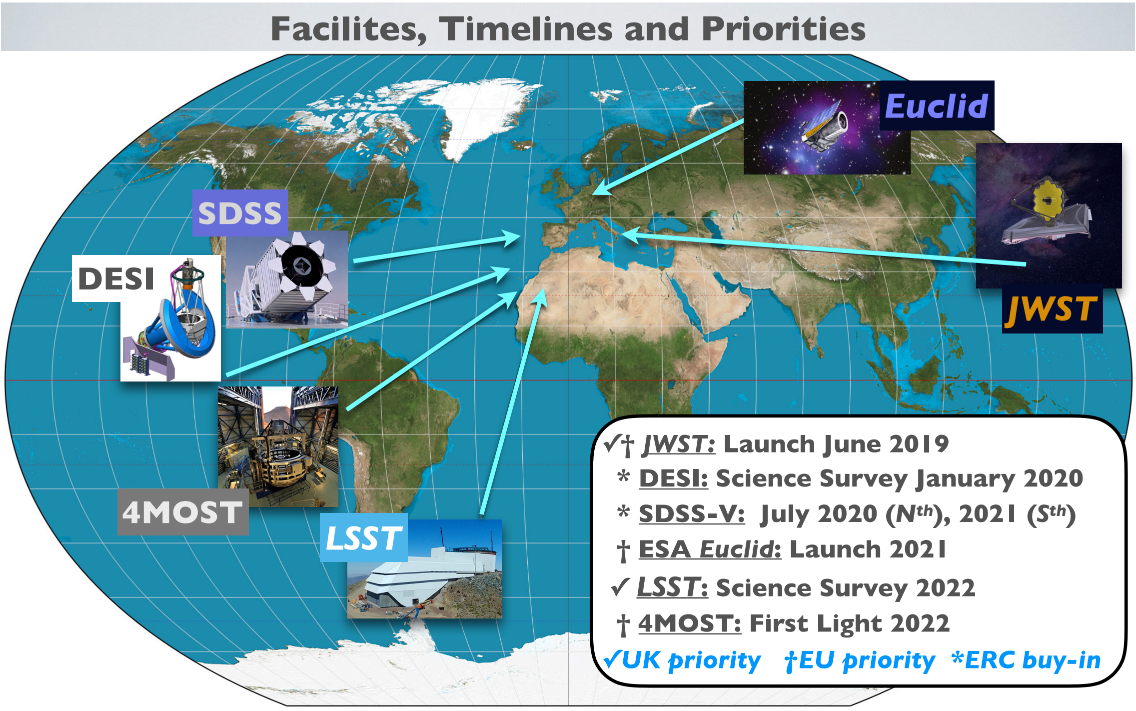

Figure 2: Facilites, Timelines and Priorities. With SDSS-V and DESI in the Northern Hemisphere and 4MOST, LSST in the South, we have full celestial sphere coverage.

mission is answering the question "How do black holes grow and shape the Universe?". ATHENA is ESA's second L-class flagship mission, due for launch in 2028.

The scope and remit of an ERC Consolidator grant will allow us to combine these data products in a manner that will not only establish the new state-of-the-art in variable extragalactic astrophysics, but it will also establish and kickstart the new field of variable extragalactic astrophysics itself.

2. Methodology

Our proposal contains six work packages that fall into three broad and complementary categories: observational studies of large numbers (millions) of objects; high-risk, very high-reward observational tudies of a small number of objects; theoretical modeling investigations. Figure 3 summarises our overall WP plan. Risks and mitigation strategies are presented for each WP, as are Key Deliverables. NPR, three PDRAs, "PDRA1", "PDRA 2", "PDRA 3", and one PhD student, "PhD1" are the personnel required to carry out these work packages.

NPR is a world-leader in the field of extragalactic observational astrophysics. NPR's research focuses on implementing novel data science algorithms and techniques in order to discover and study the physical processes in quasars. I have an exceptionally strong track record including being the lead of a science Working Group, with prodigious scientific output (over 400 published, peer-reviewed papers from that particular collaboration). **I was the Co-Founder and Chief Data Scientist of String Security Inc. where I built a predictive threat detection and remediation platform for cyber security teams by applying machine learning and predictive algorithms. Thus the P.I.'s research strengths, ability to quickly develop bleeding-edge software and science output are all ideally matched to this proposal.**

The skill set of PDRA1 would include development of the underlying tools and techniques necessary to extract meaning from large and/or complex data sets. PDRA1 would have a strong physical sciences background, and a PhD in astrophysics or computer science. The skill sets of PDRA2 would include expertise in time series analysis, primarily with optical data but potentially also in other wavebands. PDRA2 would have a PhD in astrophysics or a related field. The skill set of PDRA3 would include experience with fluid mechanics modelling and/or large computer simulations. PDRA3 would have a PhD in astrophysics, mathematics or computer

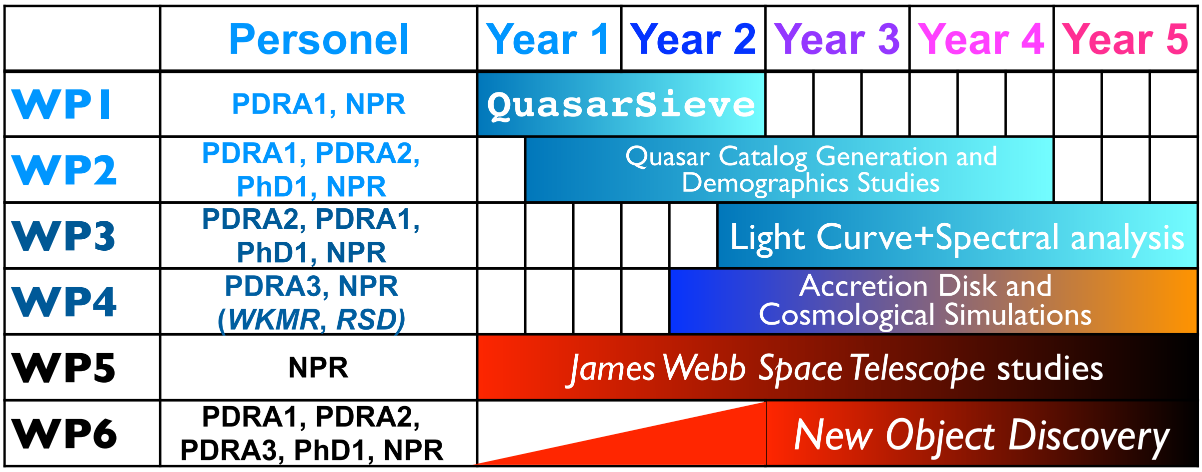

Figure 3: An overview of the WPs, with the personnel attached to each WP and a guide to their start and duration. As given by the shadings, WP1, 2 and 3 are observational studies of large numbers of objects; WP4 are theoretical modeling investigations and WP5 and 6 are high-risk, very high-reward observational studies of small numbers of objects.

science. PhD1 would have a Masters or a strong 4-year undergraduate degree in Physics or Mathematics with evidence of research-level project work.

WP1: Build QuasarSieve: In order to utilize the LSST datastream for our science goals we will build a "Stage 2 filter", which we name *QuasarSieve*. This will identify the quasars, add context, perform outburst forecasting etc. The heavy-industry computing infrastructure is being supplied by the UK LSST Data Access Center (DAC, based at the University of Edinburgh) and our task will be to build software in a timely and robust manner. This is a novel enterprise and a rate-limiting step in our overall programme, with the associated high-risk. We mitigate this risk with the data science and machine learning experience from PDRA1 and the P.I. (NPR). We thus classify **WP1 as medium-risk, high-reward. Key Deliverables:** An open-source, well-documented software package that can interact with and return data from the LSST DAC.

WP2: Quasar Catalogue Generation and Demographic studies: Building the quasar corpus and cataloguing the observational data will be a vital step for our science goals. Following on from the quasar catalogue generation, a key science output will be the study of the quasar demographics. All these are vital observational tests for galaxy formation models and theory (see WP4 below). The goal of this WP is to construct a quasar catalogue and make key observational tests. Given the P.I.s experience at these specific tasks, plus the effort level of PDRA1, PDRA2 and PhD1 **WP2 is medium-risk, high-reward. Key Deliverables:** A science-enabling compendium that will be the state-of-the-art quasar dataset for the 2020s. A suite of new, beyond-the-state-of-the-art quasar demographic measurements which are the boundary conditions for theoretical models.

WP3: Light-Curve and Spectral Analyses: Another major scientific output will be the full and detailed light-curve and spectral analyses of the conglomerate datasets. This WP will have a data science/machine learning aspect. The goal of this WP is to elucidate the physical processes that drive quasar variability and as such is significant high-reward science. This level of investigation is highly novel, though we envisage no major barriers outside of our control to achieving our science goals and PDRA1, PDRA2, as well as the P.I. (NPR) and PhD1 effort will be directed towards this. As such, **WP3 as medium-risk, high-reward. Key Deliverables:** Measurements, for the first time of how the light-curves and spectra of quasars depend on key physical quasar properties e.g. $M_{\rm SMBH}$, luminosity, $\lambda = \log(L/L_{\rm Edd})$, spin etc. These measurements will allow us to make direct comparisons to accretion disk models.

WP4: Accretion Disk and Quasar Feedback Simulations: New accretion models are needed to fully explain the "changing look" quasars and the "Quasar Viscosity Crisis". New radiation MHD codes begin to explain the observations here, but further development is needed to gain the desired deep understanding. Cosmological-scale simulations with stellar and quasar feedback are now also online. The exceedingly ambitious goal of WP5 is to develop new holistic accretion disk-to-cosmological scale simulations that explain our observational results and links them to "quasar feedback". WP4 is thus high-risk due to its novel nature and algorithmic complexity. We also envisage ramp-up time to get our theoretical simulations to the level that will be required by our beyond-the-state-of-the-art dataset. However, we mitigate this risk first by noting this will be the lead WP and top priority for PDRA3. We further mitigate this risk by invoking collaboration with accretion disk theorist Prof. Ken Rice (WKMR; Chair of Computational Astrophysics at the IfA, University of Edinburgh) and cosmological simulation expert Prof. Romeel Dave (RSD; Chair of Physics at the IfA, University of Edinburgh). Thus PDRA3, NPR, with guidance from WKMR and RSD would collaborate on this WP. We thus classify **WP4 as medium-to-high risk, very high-reward. Key Deliverables:** New accretion disk models that explain the light curve data of our beyond-the-state-of-the-art dataset. New galaxy evolution models, describing the hydrodynamics involved on galactic scales, but related to the quasar central engine.

WP5: OBSERVATIONS OF QUASARS BY THE JAMES WEBB SPACE TELESCOPE: What are the star-formation properties of luminous quasars at the peak of quasar activity? We aim to answer this by looking for the presence of polycyclic aromatic hydrocarbon (PAH) spectral features in infrared bright quasars with the *James Webb Space Telescope* (JWST). **WP5 is high risk, high-reward.** This is an ideal investigation for the JWST, but we classify this as high-risk since we have to apply for the telescope time and are not guaranteed the data. We note this WP does not impact in any direct way the other WPs and would lead to very-high gain science. **Key Deliverables:** State-of-the-art data products from the JWST, with the observational evidence and physical interpretation of how "quasar feedback" regulates galaxy formation in high-redshift quasars.

WP6: NEW OBJECT DISCOVERY: The LSST will scan the sky repeatedly, enabling it, and us, to both discover new, distant transient events and to study variable objects throughout our universe. The most interesting science may well be the discovery of new classes of objects. Suffice to say, this would be exceptionally high-reward. **WP6 is high risk, exceptionally high-reward.** We class this as high risk, since it is complex to class a WP with essentially unknown discovery potential as 'low-risk'. However, we *nota bene* that a lack of any novel discovery here would be a startling null result. **Key Deliverables:** Potential discovery of new classes of astronomical objects.

3. Resources, Survey 'buy-in' and Budget

PERSONNEL: We request the resources and support for 100% of the time and effort for the P.I. We request the resources and support for 3 Postdoctoral Research Associates (PDRAs), for a total of 10 PDRA year equivalents (3+3+4). We request the resources and support for 1 four-year PhD studentship.

SURVEY BUY-IN: We request support for the "buy-in" to two of the new surveys, SDSS-V and DESI. The costs here are €184,100 for SDSS-V and €200,100 for DESI. We ask this support to come from the "additional funds that can be made available to cover access to large facilities." We request access to these funds as it gives our project access to telescopes and data in the North and South Hemispheres for complete coverage of the celestial sphere and delivers the crucial early spectroscopy that will be vital to train, test and build our data science and machine learning codes and algorithms. We emphasise that the science return is 'exponentially' dependent on the breadth of data available and heralds a brand new regime of "several-survey" or "multi-mission" astronomy. *Buy-in here would place the P.I. and the University of Edinburgh as the only group and institute in the world to be involved in SDSS-V, DESI, 4MOST, LSST and ESA Euclid and JWST.*

COMPUTING REQUIREMENTS: With the availability of the facilities at an institute (e.g. IfA Cullen), university (e.g. Edinburgh Compute and Data Facility) and at a national (The Hartree Centre) level, the rate limiting factor will be how quickly and efficiently we can deploy our new codes and analysis.

TRAVEL: We request support for travel for all 5 members of the group, including repeat medium-term (i.e., few weeks) travel to the US and ESO Chile to work with key collaborators at critical timings for the First Light of the new telescopes.

References

K. Barbary et al. Discovery of an Unusual Optical Transient with the Hubble Space Telescope. *ApJ*, 690: 1358–1362, Jan 2009. doi: 10.1088/0004-637X/690/2/1358.

A. C. Fabian. Observational Evidence of Active Galactic Nuclei Feedback. *ARA&A*, 50:455–489, Sept 2012. doi: 10.1146/annurev-astro-081811-125521.

Z. Ivezic and J. A. for the LSST Collaboration Tyson. LSST: from Science Drivers to Reference Design and Anticipated Data Products. *ArXiv e-prints*, May 2008.

J. Kormendy and L. C. Ho. Coevolution (Or Not) of Supermassive Black Holes and Host Galaxies. *ARA&A*, 51:511–653, Aug 2013. doi: 10.1146/annurev-astro-082708-101811.

A. Lawrence. Quasar viscosity crisis. *Nature Astronomy*, 2:102–103, Jan 2018.

LSST Science Collaborations, P. A. Abell, J. Allison, S. F. Anderson, J. R. Andrew, J. R. P. Angel, L. Armus, D. Arnett, S. J. Asztalos, T. S. Axelrod, and et al. LSST Science Book, Version 2.0. *ArXiv 0912.0201v1*, Dec 2009.

C. L. MacLeod, N. P. Ross, et al. A systematic search for changing-look quasars in SDSS. *MNRAS*, 457: 389–404, March 2016. doi: 10.1093/mnras/stv2997.

I. Pâris, P. Petitjean, N. P. Ross, et al. The Sloan Digital Sky Survey Quasar Catalog: Twelfth data release. *Astron. & Astrophys.*, 597:A79, Jan 2017. doi: 10.1051/0004-6361/201527999.

N. P. Ross et al. A new physical interpretation of optical and infrared variability in quasars. *Nature Astronomy*, 2018.

L. G. Spitler et al. A repeating fast radio burst. *Nat*, 531:202–205, March 2016. doi: 10.1038/nature17168.

Section b. Curriculum vitae (max. 2 pages)

PERSONAL INFORMATION

ROSS, Nicholas P.
ORCID: 0000-0003-1830-6473
Date of birth: 16th July 1980
Nationality: British
URL for website: http://www.roe.ac.uk/~npross

EDUCATION

2003 - 2007 Ph.D., Astrophysics, Dept. of Physics, University of Durham, U.K.,
"The Clustering and Evolution of Massive Galaxies", Advisor: Prof. Tom Shanks
1999 - 2003 M.Sci., (a 4 year combined Bachelors and Masters), Physics & Astronomy,
Dept. of Physics, University of Durham, U.K. First Class Honours,

CURRENT POSITIONS

2014 - present STFC Ernest Rutherford Fellow, University of Edinburgh, U.K.

PREVIOUS POSITIONS

2016 - 2017 Co-Founder and Chief Data Scientist, String Security, Inc., San Francisco, USA
2013 - 2014 Research Assistant Professor, Dept. of Physics, Drexel University, Philadelphia, U.S.A.
2009 - 2013 Project Scientist, Physics Division, Lawrence Berkeley National Lab, Berkeley, U.S.A.
2007 - 2009 Postdoctoral Scholar, Dept. of Astronomy and Astrophysics,
Pennsylvania State University, State College, U.S.A.

FELLOWSHIPS AND AWARDS

2014 – 2019 Science & Technology Facilities Council Ernest Rutherford Fellowship

PUBLICATION RECORD

h-index of 59

Author on 118 published papers	Total number of citations:	14,942	(126.6 citations/paper)
Binomial author on 9 published papers	Total number of citations:	824	(82.4 citations/paper)

GRANTS/FUNDING OBTAINED

STFC Ernest Rutherford Fellowship (PI.)	€679,569
NASA *Spitzer Space Telescope* Cycle 9, 820 hours (Lead Co-I)	€359,745
NASA *Hubble Space Telescope* Cycle 20, 18 orbits (P.I.)	€87,330
NASA *Swift* XRT and UVOT ToO observations, Cycle 5, 17.8ks (P.I.)	€27,820
Chandra Cycle 12 Co-I Archival proposal "The Dark Matter-AGN-Weak Lensing connection" (co-I)	€41,912

SUPERVISION

2015- David Homan, University of Edinburgh PhD student
2015 Thomas Kemp, University of Edinburgh MSc student
2013 - John Timlin, Drexel University Graduate Student, Philadelphia, USA
(On Ph.D. Dissertation Committee)
2013 - 2014 Victoria Tielebein, Drexel University Senior Thesis (Final Year UG) Student,
Philadelphia PA, USA
2009 - 2012 Jessica Kirkpatrick, UC Berkeley Graduate Student, Berkeley CA, USA
2009 - 2010 Rachel Kennedy, UC Berkeley Honors Student, Berkeley CA, USA
2008 - 2009 Michael Peth, Pennsylvania State University Honors Student, State College PA, USA

APPOINTMENTS AS EXTERNAL EXAMINER

2016 Ben Chehade, PhD, *"The luminosity and redshift dependence of quasar clustering"*, University of Durham
2016 Behzad Ansarinejad, M.Res, *"An Empirical Analysis of Baryon Acoustic Oscillations in Galaxy and Quasar Clustering"*, University of Durham

TEACHING ACTIVITIES

2015, 2016 Examples Class Supervisor, *Introduction to Astrophysics*, University of Edinburgh
2009 Lead Instructor, *Astro 010: Introduction to Astronomy*, Penn State University
2007 Postgraduate Instructor, *Stars and Galaxies* course, Durham University

ORGANISATION OF SCIENTIFIC MEETINGS

2017 Co-Chair SOC *Unveiling the Physics Behind Extreme AGN Variability* University of the Virgin Islands, St. Thomas, U.S. Virgin Islands.
2016 Chair S/LOC *JWST@ROE* University of Edinburgh, International meeting
2015 Chair S/LOC *Quasar Day* University of Edinburgh, National meeting,
2014 SOC Member *Multi-wavelength Heritage of Stripe 82 Workshop*, Princeton University
2011 SOC Chair *SDSS-III BOSS Quasar Working Group* meeting, Princeton University

COMMISSIONS OF TRUST

Referee *Physical Review Letters*
Monthly Notices of the Royal Astronomical Society
The Astrophysical Journal
The Astronomical Journal
Journal of Cosmology and Astroparticle Physics

Reviewer for the NASA Postdoctoral Fellowship Program
Session Chair, "Wide-Field Surveys and QSO Physics" Parallel, UK National Astronomy Meeting, 2015.
Founder "Astronomers for America" and "Scots for Science"

MEMBERSHIPS OF SCIENTIFIC SOCIETIES

Fellow Royal Astronomical Society (since July 2004)
Full Member American Astronomical Society, (since Nov 2009)
Founder "Astronomers for America"

PRESS RELEASES

2012 BOSS Lyman-α Forest BAO Detection (incl. image credit)
2012 Quasar Broad Absorption Line Disappearance
2009 SDSS-III: BOSS First Light

SELECTED OUTREACH

2015, 2016 ROE Open Day
2013, 2014 Public Observing Nights, Drexel University
2012 LBNL Open House
2008, 2009 Penn State In-Service Workshop in Astronomy
2008, 2009 Penn State Astronomy and Astrophysics annual "AstroFest"

MAIN COLLABORATORS

John Timlin (PhD student, Drexel University)
Prof. Gordon Richards (Drexel University)
Prof. Andy Lawrence (UEDIN)
Prof. David Aspinall (School of Informatics, UEDIN)
Prof. Fred Hamann (UC Riverside)
Prof. Nadia Zakamska (Johns Hopkins)
Dr. Chelsea MacLeod (former PDRA in UEDIN research group; now PDRA CfA, Harvard)
Dr. Isabelle Pâris (formerly Aix-Marseille Université)
Prof. Patrick Petitjean (Institue d'Astrophysique de Paris)

Appendix: All on-going and submitted grants and funding of the PI (Funding ID)

Mandatory information (does not count towards page limits)

On-going Grants

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*
STFC Ernest Rutherford Fellowship (ERF)	STFC, U.K.	679,569	01-OCT-2014 to 30-SEP-2019	To perform world leading research, either independently, or with collaborators of the PIs choice.	Current ERF grant has research linked to, but in no way overlapping with ERC proposal. Latest results from current research will be the preliminary data for the novel research proposed here.

Grant applications

n/a

Section c. Early Achievements Track-record (max. 2 pages)

My (*NPR*) research focuses on implementing novel algorithms and techniques in order to discover and study the physical processes in quasars. After spending 7 years in the United States (working at Penn State, Lawrence Berkeley National Lab and then as an Assistant Research Professor at Drexel University) I returned to the U.K. with the award of an STFC Ernest Rutherford Fellowship, one of the most senior personal astrophysics fellowships in the UK, which has an application oversubscription of ~20:1 and is over £500,000 (€630,000) on award.

I have established myself as an independent lead investigator and have led the discovery of new types of quasars: the **Extremely Red Quasars**, (*NPR* et al. 2015, MNRAS) and with my research team leading the discovery of the first sample of the new **Changing Look Quasars** (MacLeod, *NPR* et al. 2016, MNRAS). My team has also led the production of the largest areal space-based survey using NASA's *Spitzer Space Telescope* (Timlin, *NPR* et al. 2016, ApJS). This has led to the ground breaking and novel first measurement of infrared quasar clustering at high-redshift (Timlin, *NPR* et al. 2018, ApJ, accepted).

The PI led the team that was responsible for obtaining the data necessary for the SDSS-III BOSS cosmology experiment, leading to the first measurement of baryon acoustic oscillations at high-redshift. The PI's leadership includes leading science teams such as the **SDSS-III BOSS Quasar Science Working Group** which has resulted in an *extremely high publication output including 118 peer-review journal articles with 15,000 citations and an h-index of 59 (SAO/NASA Astrophysics Data System).* This is world-leading for any astrophysicist and virtually unparalleled by my contemporaries at a similar career stage.

I am an expert in a suite of research methodologies in **data science** and machine learning. In particular, at the heart of my research with the SDSS-BOSS project, was anomaly detection in extremely large datasets. I was a co-founder and Chief Data Scientist of, **String Security *Inc.*** There I built a predictive threat detection and remediation platform for cyber security teams by applying machine learning and predictive algorithms. The PI is currently in discussion with the School of Informatics at the UoE on potential joint projects and research avenues.

Relevant Selected Journal Publications *(N.B.* None with PhD supervisor, ***citations in red****)*

Pâris, Isabelle; Petitjean, Patrick; **Ross, Nicholas P.** et al "*The Sloan Digital Sky Survey Quasar Catalog: Twelfth data release", 10.1051/0004-6361/201527999,* **2017A&A...597A..79P** **(96)** Production of the current state-of-the-art quasar catalogue with associated metadata.

Hamann, Fred; Zakamska, Nadia L.; **Ross, Nicholas P.** et al. *"Extremely red quasars in BOSS"*, 10.1093/mnras/stw2387, **2017MNRAS.464.3431H**, **(13)** Follow-up analysis to the Ross et al. (2015) discovery paper.

Timlin, John D.; **Ross, Nicholas P.** et al. "*SpIES: The Spitzer IRAC Equatorial Survey",* 10.3847/0067-0049/225/1/1 **2016ApJS..225....1T**, **(13)** Survey paper and catalogue for the largest areal *Spitzer Space Telescope* programme.

MacLeod, Chelsea L.; **Ross, Nicholas P** et al. "*A systematic search for changing-look quasars in SDSS",* 10.1093/mnras/stv2997, **2016MNRAS.457..389M, (43)** Field-leading paper for CLQ studies; first systematic search with detailed theoretical interpretation.

Ross, Nicholas P. et al. *"Extremely red quasars from SDSS, BOSS and WISE: classification of optical spectra"*, 10.1093/mnras/stv1710 **2015MNRAS.453.3932R**, **(25)** The discovery paper for the new class of "Extremely Red Quasars".

Font-Ribera, Andreu; Kirkby, David; Busca, Nicolas; Miralda-Escudé, Jordi; **Ross, Nicholas P.** et al. "*Quasar-Lyman α forest cross-correlation from BOSS DR11: Baryon Acoustic Oscillations",* 10.1088/1475-7516/2014/05/027 **2014JCAP...05..027F** **(166)** Ground-breaking first detection of the "Baryon Acoustic Oscillation" phenomena in the quasar population.

Ross, Nicholas P. et al. "*The SDSS-III Baryon Oscillation Spectroscopic Survey: The Quasar Luminosity Function from Data Release Nine*", 10.1088/0004-637X/773/1/14 **2013ApJ...773...14R**, **(99)** Critical demographic "1-point" measurement of the BOSS quasar Sample (was a BOSS "Key Project").

Ross, Nicholas P et al. "*The SDSS-III Baryon Oscillation Spectroscopic Survey: Quasar Target Selection for Data Release Nine*", 10.1088/0067-0049/199/1/3, **2012ApJS..199....3R** **(179)** Overview of the work my team lead and a opus of using novel machine learning techniques for astrophysics research.

Pâris, I.; Petitjean, P.; Aubourg, É.; Bailey, S.; **Ross, Nicholas P.** et al. "*The Sloan Digital Sky Survey Quasar Catalog: Ninth Data Release*", 10.1051/0004-6361/201220142, **2012A&A...548A..66P** **(184)** Production of the first catalogue and data release from the SDSS-III BOSS Quasar Survey.

Schneider, Donald P.; Richards, Gordon T.; Hall, Patrick B.; Strauss, Michael A.; Anderson, Scott F.; Boroson, Todd A.;, **Ross, Nicholas P.** et al. "*The Sloan Digital Sky Survey Quasar Catalog. V. Seventh Data Release*", 10.1088/0004-6256/139/6/2360, **2010AJ....139.2360S** **(588)** Production of the previous state-of-the-art quasar catalogue, with associated metadata.

Ross, Nicholas P et al. "*Clustering of Low-redshift (z <= 2.2) Quasars from the Sloan Digital Sky Survey,* 10.1088/0004-637X/697/2/1634, **2009ApJ...697.1634R** **(158)** Critical demographic `2-point' measurement of the SDSS Quasar Sample (was SDSS Quasar "Key Project").

PRIZES AND AWARDS

2014 - 2019	STFC Ernest Rutherford Senior Fellowship
2009 - 2016	*Architect* SDSS-III: Baryon Oscillation Spectroscopic Survey (BOSS)
2003 - 2008	PPARC Student Fellowship, *Durham University*

SELECTED LEADERSHIP

2018	P.I. Liverpool Telescope program: *The Optical Monitoring of IR-variable Quasar*s
2018 -	P.I. *JWST* Cycle 1 GO program: *Quasar Physics with the MIRI MRS* (to be submitted)
2017 -	P.I. WISE W4 Compendium (WW4C)
2016 - 2017	Co-founder and Chief Data Scientist of *String Security Inc.*
2014 - 2019	P.I., STFC Ernest Rutherford Fellowship
2013 - 2016	Co-P.I., *Spitzer Space Telescope* program "SpIES: The Spitzer-IRAC Equatorial Survey"'
2012 - 2014	Co-P.I., *Hubble Space Telescope,* program "High-Luminosity Obscured Quasars at z~2.5"
2011	Chapter Editor, *BigBOSS* NOAO Proposal, arxiv.org/abs/1106.1706v1
2011	P.I., SDSS-IV: BOSS-Plus (accepted Nov 2011; merged into SDSS-IV: eBOSS)
2009 - 2012	Chair, SDSS-III BOSS Quasar Working Group
2008 - 2010	Lead, SDSS-III BOSS Quasar Target Selection Group
2008 - 2010	P.I., NASA *Swift* Cycle 5 Long-term local AGN monitoring program

SELECTED PRESENTATIONS

2017 Nov	*Dealing With Data 2017 Workshop*	Selected Oral Contribution
2017 Jul	*Unveiling the Physics Behind Extreme AGN Variability*	Conference Summary
2017 May	University of Cambridge	Galaxies Discussion Group
2016 Jun	*JWST@ROE* conference	Contributed talk
2016 May	University of Michigan	Astrophysics Seminar
2016 May	Great Lakes Quasar Symposium	Oral Contribution
2015 Sep	*Multiwavelength AGN*, Crete	Invited Review
2015 Apr	Adler Planetarium, Chicago	Astrophysics Seminar
2015 Jan	225th AAS, Seattle	Special Session talk
2014 Sep	*Heritage of Stripe 82*, Princeton University	Invited talk
2014 May	Harvard University	HEAD talk
2014 Apr	University of Pennsylvania	Astrophysics Seminar
2013 May	Stanford University	KIPAC Talk
2011 Jul	Oxford University	BICAP Cosmology Seminar
2011 May	Yale University	YCAA Seminar