Horizon 2020

Excellent Science

Call: ERC-2015-STG

Topic: ERC-StG-2015

Type of action: ERC-STG

Proposal number: 678679

Proposal acronym: MIQSOS

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How to fill in the forms

The administrative forms must be filled in for each proposal using the templates available in the submission system. Some data fields in the administrative forms are pre-filled based on the previous steps in the submission wizard.

1 - General information

Topic ERC-StG-2015

Type of action ERC-STG

Call identifier ERC-2015-STG

Acronym* MIQSOS

Proposal title* Connecting quasars with galaxy formation via Mid-infrared observations and Next Generation Telescopes

Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &

Duration in months* *60*

Primary ERC Review Panel* PE9 - Universe Sciences

Secondary ERC Review Panel (if applicable)

ERC Keyword 1* *Formation and evolution of galaxies*

Please select, if applicable, the ERC keyword(s) that best characterise the subject of your proposal in order of priority.

ERC Keyword 2 *Not applicable*

ERC Keyword 3 *Not applicable*

ERC Keyword 4 *Not applicable*

Free keywords *In addition, please enter free text keywords that you consider best characterise the scope of your research proposal. The choice of keywords should take into account any multi-disciplinary aspects of the proposal.*

Proposal ID **678679** *Acronym* **MIQSOS**

Abstract*

The two key sources of energy in a galaxy are nuclear fusion in stars, and the energy liberated in a strong gravitational field, e.g. by accretion onto a supermassive black hole (SMBH).The rate of stellar and gravitational energy production are observed to have evolved in a similar fashion, with both the cosmic star-formation rate density and luminous active galactic nuclei (AGN) activity peaking around 3 Gyr after the Big Bang.

Furthermore, the link between massive galaxies and the central SMBHs that seem ubiquitous in them is now thought to be vital to the understanding of galaxy formation and evolution. This has led to the proposal that the supermassive black hole, when accreting, has an influence on its host galaxy by the means of some regulatory ``feedback'' mechanism(s).

However, the details of the physical processes involved in AGN feedback are still disputed and, moreover, direct observational evidence for AGN feedback in the early universe is heavily conspicuous by its absence. As such, a major source of uncertainty in our current understanding of galaxy evolution is how supermassive black holes influence, and potentially regulate, their host galaxies.

The primary aim of this proposal is to elucidate the nature of quasar activity and AGN feedback, particularly at high-redshift. Using new optical and mid-infrared datasets that the P.I. has unique access to, the accretion history of the Universe at redshifts z=2-7 will be established. These measurements will constrain the energetics of black hole mass build-up, will test feedback models at high-z and lead to a deeper understanding of the physical processes involved in galaxy formation and evolution. The P.I. is a world leader in QSO surveys and IR AGN physics, and these investigations will set the scene for the early science from the next generation of telescopes, in particular the James Webb Space Telescope.

Remaining characters 96

In order to best review your application, do you agree that the above non-confidential proposal title and abstract can be used, without disclosing your identity, when contacting potential reviewers?*	(•) Yes ( ) No
Has this proposal (or a very similar one) been submitted in the past 2 years in response to a call for proposals under the 7th Framework Programme, Horizon 2020 or any other EU programme(s)?	( ) Yes (•) No

Declarations

1) The Principal Investigator declares to have the explicit consent of all applicants on their participation and on the content of this proposal.*	☒
2) The information contained in this proposal is correct and complete.	☒
3) This proposal complies with ethical principles (including the highest standards of research integrity — as set out, for instance, in the European Code of Conduct for Research Integrity — and including, in particular, avoiding fabrication, falsification, plagiarism or other research misconduct).	☒

4) The Principal Investigator hereby declares that *(please select one of the three options below)*:

- in case of multiple participants in the proposal, the coordinator has carried out the self-check of the financial capacity of the organisation on http://ec.europa.eu/research/participants/portal/desktop/en/organisations/lfv.html. Where the result was “weak” or “insufficient”, the Principal Investigator confirms being aware of the measures that may be imposed in accordance with the H2020 Grants Manual (Chapter on Financial capacity check).	○
- in case of multiple participants in the proposal, the Principal Investigator is exempt from the financial capacity check being a public body including international organisations, higher or secondary education establishment or a legal entity, whose viability is guaranteed by a Member State or associated country, as defined in the H2020 Grants Manual (Chapter on Financial capacity check).	○
- in case of a sole participant in the proposal, the applicant is exempt from the financial capacity check.	◉
5) The Principal Investigator hereby declares that each applicant has confirmed to have the financial and operational capacity to carry out the proposed action. Where the proposal is to be retained for EU funding, each beneficiary applicant will be required to present a formal declaration in this respect.	☒

The Principal Investigator is only responsible for the correctness of the information relating to his/her own organisation. Each applicant remains responsible for the correctness of the information related to him and declared above. Where the proposal to be retained for EU funding, the coordinator and each beneficiary applicant will be required to present a formal declaration in this respect.

According to Article 131 of the Financial Regulation of 25 October 2012 on the financial rules applicable to the general budget of the Union (Official Journal L 298 of 26.10.2012, p. 1) and Article 145 of its Rules of Application (Official Journal L 362, 31.12.2012, p.1) applicants found guilty of misrepresentation may be subject to administrative and financial penalties under certain conditions.

Personal data protection

Your reply to the grant application will involve the recording and processing of personal data (such as your name, address and CV), which will be processed pursuant to Regulation (EC) No 45/2001 on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data. Unless indicated otherwise, your replies to the questions in this form and any personal data requested are required to assess your grant application in accordance with the specifications of the call for proposals and will be processed solely for that purpose. Details concerning the processing of your personal data are available on the privacy statement. Applicants may lodge a complaint about the processing of their personal data with the European Data Protection Supervisor at any time.

Your personal data may be registered in the Early Warning System (EWS) only or both in the EWS and Central Exclusion Database (CED) by the Accounting Officer of the Commission, should you be in one of the situations mentioned in:

- the Commission Decision 2008/969 of 16.12.2008 on the Early Warning System (for more information see the Privacy Statement), or
- the Commission Regulation 2008/1302 of 17.12.2008 on the Central Exclusion Database (for more information see the Privacy Statement).

2 - Administrative data of participating organisations

Host Institution

PIC	***Legal name***
999974941	*THE UNIVERSITY OF EDINBURGH*

Short name: UEDIN

Address of the organisation

Street OLD COLLEGE, SOUTH BRIDGE

Town EDINBURGH

Postcode EH8 9YL

Country United Kingdom

Webpage www.ed.ac.uk

Legal Status of your organisation

Research and Innovation legal statuses

Public body .... yes

Legal person .... yes

Non-profit .... yes

International organisation .... no

International organisation of European interest .... no

Secondary or Higher education establishment .... yes

Research organisation .... yes

Small and Medium-sized Enterprises (SMEs) .... no

Nace code 853 -

Department(s) carrying out the proposed work

Department 1

Department name	Institute for Astronomy
	☐ Same as organisation address
Street	Royal Observatory, Blackford Hill
Town	EDINBURGH
Postcode	EH9 3HJ
Country	United Kingdom

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Principal Investigator

The following information of the Principal Investigator is used to personalise the communications to applicants and the evaluation reports. Please make sure that your personal information is accurate and please inform the ERC in case your e-mail address changes by using the call specific e-mail address:

For Starting Grant Applicants: ERC-2015-StG-applicants@ec.europa.eu

The name and e-mail of contact persons including the Principal Investigator, Host Institution contact are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of contact persons, please save and close this form, then go back to Step 4 of the submission wizard and save the changes.

Researcher ID	*If you have a researcher identifier number (e.g. ResearcherID, ORCID) please enter it here.*		
Last Name*	Ross	Last Name at Birth	Ross
First Name(s)*	Nicholas	Gender*	(•) Male ( ) Female
Title	Dr.	Country of residence*	United Kingdom
Nationality*	United Kingdom	Country of Birth*	United Kingdom
Date of Birth* (DD/MM/YYYY)	16/07/1980	Place of Birth*	EDINBURGH

Contact address

☐ Same as organisation address

Current organisation name	Institute for Astronomy		
Current Department/Faculty/Institute/ Laboratory name	Royal Observatory, Edinburgh		
Street	Blackford Hill		
Postcode/Cedex	EH9 3HJ	Town*	EDINBURGH
Phone*	+44 (0) 131-668 8351	Country*	United Kingdom
Phone2 / Mobile	+xxxx xxxxxxxxxxxx		
E-mail	npross@lbl.gov		

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Contact address of the Host Institution and contact person

The name and e-mail of Host Institution contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of Host Institution, please save and close this form, then go back to Step 4 of the submission wizard and save the changes. Please note that the submission is blocked without a contact person and e-mail address for the Host Institution.

Organisation Legal Name **THE UNIVERSITY OF EDINBURGH**

First name* **Angela** Last name* **Noble**

E-Mail* **angela.noble@ed.ac.uk**

Position in org. *Manager, Europe*

Department *Edinburgh Research and Innovation*

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Country United Kingdom

Phone +441316509024 Phone2/Mobile *+xxxx xxxxxxxxxxx*

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Nathalie	Dupin	nohd@roe.ac.uk	
ERI	Europe	europe@eri.ed.ac.uk	

3 - Budget

Participant Number in this proposal	Organisation Short Name	Organisation Country	Total eligible costs/€ (including 25% indirect costs) ?	Requested grant/€
1	UEDIN	UK	1 312 283	1 312 283
Total			1 312 283	1 312 283

4 - Ethics issues table

1. HUMAN EMBRYOS/FOETUSES		Page
Does your research involve Human Embryonic Stem Cells (hESCs)?	◯ Yes ◉ No	
Does your research involve the use of human embryos?	◯ Yes ◉ No	
Does your research involve the use of human foetal tissues / cells?	◯ Yes ◉ No	
2. HUMANS		Page
Does your research involve human participants?	◯ Yes ◉ No	
Does your research involve physical interventions on the study participants?	◯ Yes ◉ No	
Does it involve invasive techniques?	◯ Yes ◉ No	
3. HUMAN CELLS / TISSUES		Page
Does your research involve human cells or tissues (other than from Human Embryos/ Foetuses, i.e. section 1)?	◯ Yes ◉ No	
4. PERSONAL DATA (ii)		Page
Does your research involve personal data collection and/or processing?	◯ Yes ◉ No	
Does your research involve further processing of previously collected personal data (secondary use)?	◯ Yes ◉ No	
5. ANIMALS (iii)		Page
Does your research involve animals?	◯ Yes ◉ No	

6. THIRD COUNTRIES		Page
Does your research involve non-EU countries?	◯ Yes ◉ No	
Do you plan to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)? (v)	◯ Yes ◉ No	
Do you plan to import any material from non-EU countries into the EU? *For data imports, please fill in also section 4.* *For imports concerning human cells or tissues, fill in also section 3.*	◯ Yes ◉ No	
Do you plan to export any material from the EU to non-EU countries? *For data exports, please fill in also section 4.* *For exports concerning human cells or tissues, fill in also section 3.*	◯ Yes ◉ No	
If your research involves low and/or lower middle income countries, are benefits-sharing measures foreseen? (vii)	◯ Yes ◉ No	
Could the situation in the country put the individuals taking part in the research at risk?	◯ Yes ◉ No	
7. ENVIRONMENT & HEALTH and SAFETY See legal references at the end of the section. (vi)		Page
Does your research involve the use of elements that may cause harm to the environment, to animals or plants? *For research involving animal experiments, please fill in also section 5.*	◯ Yes ◉ No	
Does your research deal with endangered fauna and/or flora and/or protected areas?	◯ Yes ◉ No	
Does your research involve the use of elements that may cause harm to humans, including research staff? *For research involving human participants, please fill in also section 2.*	◯ Yes ◉ No	
8. DUAL USE (vii)		Page
Does your research have the potential for military applications?	◯ Yes ◉ No	
9. MISUSE		Page
Does your research have the potential for malevolent/criminal/terrorist abuse?	◯ Yes ◉ No	
10. OTHER ETHICS ISSUES		Page
Are there any other ethics issues that should be taken into consideration? Please specify	◯ Yes ◉ No	

I confirm that I have taken into account all ethics issues described above and that, if any ethics issues apply, I will complete the ethics self-assessment and attach the required documents. ☒

5 - Call specific questions

Academic Training	
Are you a medical doctor or do you hold a degree in medicine? Please note that if you have also been awarded a PhD, your medical degree may be your first eligible degree.	◯ Yes ◉ No
Date of earliest award (PhD or equivalent)* - DD/MM/YYYY	11/01/2008
With respect to the earliest award (PhD or equivalent), I request an extension of the eligibility window, (indicate number of days) [see the ERC 2015 Work Programme and the Information for Applicants to the Starting and Consolidator Grant 2015 Calls].	◯ Yes ◉ No

Eligibility	
I acknowledge that I am aware of the eligibility requirements for applying for this ERC call as specified in the ERC Work Programme 2015, and certify that, to the best of my knowledge my application is in compliance with all these requirements. I understand that my proposal may be declared ineligible at any point during the evaluation or granting process if it is found not to be compliant with these eligibility criteria.*	☒

Data-Related Questions and Data Protection (Consent to any question below is entirely voluntary. A positive or negative answer will not affect the evaluation of your project proposal in any form and will not be communicated to the evaluators of your project.)	
For communication purposes only, the ERC asks for your permission to publish your name, the proposal title, the proposal acronym, the panel, and host institution, should your proposal be retained for funding.	◉ Yes ◯ No
Some national and regional public research funding authorities run schemes to fund ERC applicants that score highly in the ERC's evaluation but which can not be funded by the ERC due to its limited budget. In case your proposal could not be selected for funding by the ERC do you consent to allow the ERC to disclose the results of your evaluation (score and ranking range) together with your name, non-confidential proposal title and abstract, proposal acronym, host institution and your contact details to such authorities?	◉ Yes ◯ No
The ERC is sometimes contacted for lists of ERC funded researchers by institutions that are awarding prizes to excellent researchers. Do you consent to allow the ERC to disclose your name, non-confidential proposal title and abstract, proposal acronym, host institution and your contact details to such institutions?	◉ Yes ◯ No
The Scientific Council of the ERC has developed a monitoring and evaluation strategy in order to help it fulfil its obligations to establish the ERC's overall strategy and to monitor and quality control the programme's implementation from the scientific perspective. As provided by section 3.10 of the ERC Rules for Submission, a range of projects and studies may be initiated for purposes related to monitoring, study and evaluating the implementation of ERC actions. Do you consent to allow the third parties carrying out these projects and studies to process the content of your proposal including your personal data and the respective evaluation data? The privacy statement on grants (http://erc.europa.eu/document-library) explains further how your personal data is secured.	◉ Yes ◯ No

Excluded Reviewers

You can provide up to three names of persons that should not act as an evaluator in the evaluation of the proposal for potential competitive reasons.

MIQSOs: Connecting Quasars with galaxy formation via Mid-infrared observations and Next Generation Telescopes

In the local Universe, there is a link between the key properties of massive galaxies, such as bulge mass, and their central supermassive black holes. This has led to the proposal that the supermassive black hole, when accreting, has an influence on its host galaxy by the means of some regulatory "feedback" mechanism(s). However, the details of the physical processes involved in active galactic nuclei (AGN) feedback are still disputed and, moreover, direct observational evidence for AGN feedback in the early universe is heavily conspicuous by its absence. As such, a major source of uncertainty in our current understanding of galaxy evolution is how supermassive black holes influence, and potentially regulate, their host galaxies.

The primary aim of this proposal is to elucidate the nature of quasar activity and AGN feedback, particularly at high-redshift. Using new optical and mid-infrared datasets, that the P.I. has unique access to, the accretion history of the Universe at redshifts $z = 2 - 7$ will be established. These measurements will constrain the energetics of black hole mass build-up, will test feedback models at high-z and lead to a deeper understanding of the physical processes involved in galaxy formation and evolution.

Introduction: The two key sources of energy in a galaxy are nuclear fusion in stars, and the energy liberated in a strong gravitational field, e.g. by accretion onto a supermassive black hole (SMBH). The rate of stellar and gravitational energy production are observed to have evolved in a similar fashion, with both the cosmic star-formation rate density and luminous AGN activity peaking around 3 Gyr after the Big Bang at $z \sim 2$ ([1], [2]). Furthermore, the link between massive galaxies and the central SMBHs that seem ubiquitous in them is now thought to be vital to the understanding of galaxy formation and evolution ([3], [4]). However, aside from knowing that both processes require a fuel supply, the details of the physical processes that potentially connect stars and black holes in galaxies are not well understood. As such, huge observational and theoretical effort has been invested in trying to measure and understand the physics involved in these enigmatic systems.

SDSS, BOSS and the Quasar Luminosity Function: A key observational resource in making progress in the investigation of supermassive black hole activity is very wide-field quasar surveys. Quasars are the subset of the most luminous AGN and the state-of-the-art in quasar surveys is the Sloan Digital Sky Survey (SDSS; [5]) and the Baryon Oscillation Spectroscopic Survey (BOSS; [6], [7]). Together these provide a powerful database of over 400,000 spectroscopically confirmed quasars waiting to be fully exploited. My leading position within the SDSS-III: BOSS project has allowed me to create, and exploit, the datasets needed for my science goals. For instance, I was the scientific lead for the quasar target selection ([8]; Fig. 1, *left*) needed to find a high density of $z > 2$ quasars, vital for the first measurement of baryon acoustic oscillations in the Lyman-α Forest ([9], [10]).

I also led the analysis for the BOSS Data Release Nine (DR9) quasar luminosity function (QLF, [2]; Fig. 1, *center*). This is a key measurement since it uncovered the "break luminosity" (L^*) in the double-power law form of the $2 < z < 4$ QLF for the first time. This is important since the majority of black hole mass build-up happens for AGN at the break luminosity, and this epoch is where quasar activity peaks. I showed that 'pure luminosity evolution' is still an adequate description of the QLF at $z \lesssim 2$ - only changing to a 'luminosity dependent' density evolution at $z \gtrsim 2$. What drives this evolution, the directly related fueling mechanism (e.g., mergers vs. secular processes) and the feedback physics invoked, are key outstanding issues and will be tackled by this proposal.

A full census of the Quasar Population: A pillar of our current understanding of the buildup of SMBHs over cosmic time is the "Sołtan argument" ([12]) which relates the integrated quasar luminosity density to the mass density of relic black holes in the local Universe. However, it is *crucial* that this census of quasar emission includes contributions from obscured quasars, which are accreting SMBHs where gas and dust block our line-of-sight to the central engine. This obscuration could arise from a torus (e.g., [13], [14]) with unobscured and obscured quasars representing different viewing angles, or, represent different phases of quasar evolution ([15], [16], [17]), with all quasars passing

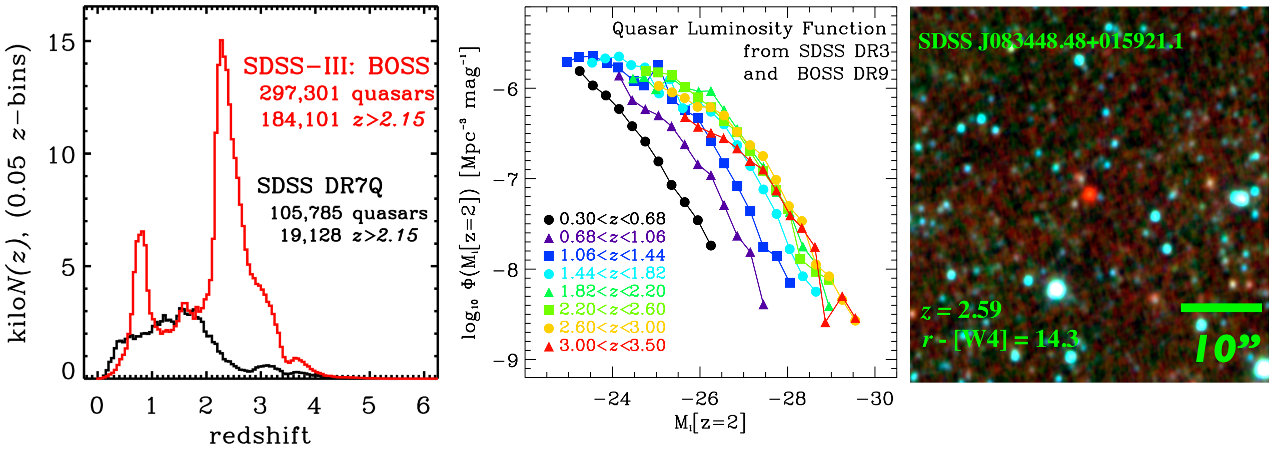

Figure 1: *(Left)* Redshift distributions of quasars from SDSS (black) and BOSS (red, [8]). *(Centre)* New measurement of the optical QLF from [2] extending the SDSS DR3 results from [11] and finding a clear break in the QLF at all redshifts up to $z = 3.5$. *(Right)* A WISE 3.4, 4.6 and 12μm image of a $z = 2.59$ extremely red quasar, selected on its $r - [22]$ colour, discovered by [24]. This object has a 22μm flux indicative of $L_{IR} \gtrsim 10^{14} L_\odot$, and one interpretation could be we are witnessing the "birth" of an unobscured quasar.

through an obscured phase before outflows expel the obscuring material. Observationally, obscured AGN are *at least as common* as unobscured AGN in the local Universe. If quasars at high-z are similarly obscured, our understanding of SMBH growth needs to be substantially revised.

Critically, new estimates of the local black hole mass density ([18], [19], [20]) suggest it is up to ∼5 times higher than previously determined, which requires a corresponding increase in the amount of accretion. This can be explained by either super-Eddington accretion ([21]) and/or a population of heavily obscured AGN ([22]). Thus accounting for this "missing accretion", and the energetics associated with it, is an outstanding issue and a key ingredient required for any AGN feedback model.

Furthermore, I am currently leading the investigations into a new class of object, the "extremely red quasars" that have optical spectroscopy from SDSS/BOSS, and $r - [22\mu\text{m}] > 14$ colours (i.e., $F_\nu(22\mu\text{m})/F_\nu(r) \gtrsim 1000$) from the Wide-field Infrared Survey Explorer (WISE; [23], [24]) satellite (Fig. 1, *right*). The physical nature of these objects is currently uncertain, but new infrared spectroscopy shows these objects may have interesting gas kinematics and very strong outflows, suggesting this is a "transition population", with the quasar 'breaking out' of its obscured phase.

Due to the dust reprocessing of UV/optical photons from an active AGN, mid-infrared observations are the key to identifying even the most heavily obscured quasars, e.g., [25-31]. Thus, the combination of optical spectroscopy and mid-IR photometry over large areas of the sky is ideally suited to detecting high-redshift luminous AGN as well as highly obscured AGN, ready to complete the quasar census.

AGN Feedback at High-z: Modern galaxy formation theory strongly suggests that the active, i.e., quasar, phase of black hole activity has a controlling effect on shaping the global properties of the host galaxies. As such, "AGN feedback" (kinetic and radiative energy impacting galaxy-scale gas/dust) is one of the hottest topics in galaxy evolution today and has become a routinely invoked ingredient for galaxy formation models. The epoch around $z \sim 2$ is particularly important for quasar feedback studies because it marks the peak of both star formation and quasar activity in the universe, and thus high-z, luminous (obscured) quasars are the most likely sites where powerful feedback takes place. This feedback can drive strong winds that clear the galaxy of gas, shutting-off star formation ([17], [32]). However, direct observations of quasars exhibiting outflows in situ are challenging and lacking (especially at high redshift), and as a result, the physical details of these processes are poorly known.

There is however, another avenue that can bring insight, and that is the demographic study of the environments of the quasars, i.e. via a measure of their clustering. Different AGN feedback models, in particular from [33], predict similar clustering behaviour at $z < 2$ where observations indicate that quasars with a range of BH masses and accretion rates must be hosted by similar, moderately massive structures. However, the feedback models diverge at higher redshift since quasars with lower BH masses and/or accretion rates are not expected to inhabit the extremely massive structures occupied by SDSS quasars (which represent the most massive $z > 3$ BHs accreting at Eddington, [34]). To break this degeneracy we must probe fainter than L^* at beyond $z = 3$.

Key Objectives: This proposal aims to address the following key questions:

1. Do we have a complete census of the accreting quasar population across the redshift range $z = 2 - 7$?

2. How much accretion and black hole mass build up occurs in the obscured phase, and how does this influence the host galaxy?

3. At $z > 2$, what environments are obscured and unobscured quasars found in?

4. Are the "Extremely Red Quasars" an important transition population?

Methodology

Key Dataset 1: SDSS-III BOSS With the full 10,000 deg^2 of spectroscopy obtained, the observations for SDSS-III: BOSS were completed in mid-2014. The final BOSS quasar sample contains just under 300,000 quasars down to a magnitude limit of $g \approx 22.0$ of which 190,000 have $2.0 < z < 3.5$. I have had significant input and responsibility helping prepare the final BOSS quasar catalogues, and as such, have a very deep knowledge of this sample.

Key Dataset 2: SpIES I am the lead co-PI of the *Spitzer*-IRAC Equatorial Survey (SpIES), which is a new deep 3.6μm and 4.5μm imaging survey designed to discover obscured and unobscured quasars across 100 deg^2 of the SDSS Stripe 82 field. SpIES is an Exploration Science program that is the largest areal survey ever undertaken by *Spitzer*, and its scientific goals are to study the respective QLFs and clustering measurements to $z \sim 4$, and potentially discover a suite of very high redshift quasars. To make significant advancement in these areas, SpIES will probe ∼1 dex fainter than L^* at $z \sim 3$ and as faint as L^* at $z \sim 4$. SpIES data taking has just finished (late 2014) and I am leading the production of the final catalogues, which are due to appear in 2015, ready for science exploitation.

Key Dataset 3: WISE The WISE satellite has been revived for a new 3-year mission that started in late 2013. The new survey uses the shorter 3.4 and 4.6μm bands and a [3.4]-[4.6] colour selection has been proven to be highly efficient and complete for selecting AGN ([35], [36]) up to very high redshift ($z \sim 6 - 7$; [37]). A new public WISE data release, including the new data is scheduled for ∼mid-2015.

Key Dataset 4: SDSS-IV The current 2.5m Sloan telescope and BOSS spectrograph system will remain state-of-the-art for at least for the mid-term. As such, the immediate future of spectroscopic surveys is the fourth installment of the Sloan Digital Sky Survey, SDSS-IV.

SDSS-IV: eBOSS: The Extended Baryon Oscillation Spectroscopic Survey (eBOSS) is addressing the issue of the cosmological expansion in unexplored redshift regimes — including the epoch of transition from deceleration to acceleration. To do so, eBOSS will obtain spectra for nearly 700,000 quasars across the redshift range $1.0 < z < 3.5$, over a footprint of 7,500 deg^2. A new sample of $g = 22.0$ "mid-redshift" quasars (630,000 objects in the range $1 < z < 2.2$), will complement the bright SDSS in luminosity range, and the SDSS-III: BOSS $z > 2.2$ "high-redshift" sample in z-range. The eBOSS survey started in September 2014 for a 6 year duration.

SDSS-IV: TDSS: The Time Domain Spectroscopic Survey (TDSS) is another SDSS-IV survey and will select time-variable targets for spectroscopic follow-up. These targets will include quasars and several classes of variable stars, either of which may well reveal previously unidentified phenomena.

I performed 'Key Project' science investigations with SDSS ([38]) and was the Chair of the SDSS-III Quasar Working Group. Critically, however, by returning to Europe, I am no longer part of SDSS-IV and thus currently not leading new analysis in SDSS-IV. *To build on my previous investment of effort and expertise, and to restore collaboration and data access, collaboration "buy-in" is required. Part of this grant request is for this SDSS-IV 'buy-in', which allows data rights and collaboration access to the P.I.* ***and their associated PDRAs and PhD students.***

MIQSOs Project 1: A full census of Quasars at $z = 2 - 7$ (3 year PDRA project)

This project will leverage the optical and new mid-infrared datasets to make a complete census of the $z = 2-7$ quasar population in order to accurately account for supermassive black hole mass build-up.

Science Goal 1: Exploitation of the SDSS+BOSS optical spectroscopy, and the SpIES+WISE MIR data in order to make a mid-infrared quasar luminosity function (QLF) measurement. The QLF is a convolution of the: *(i)* black hole mass function; *(ii)* the efficiency of matter accretion and *(iii)* obscuration fraction, all of which depend (in a poorly understood way) on luminosity and redshift. The current state-of-the-art optical QLF measurements at high-redshift, $z \gtrsim 2$, where model discrimination power is best, are hampered by not knowing the obscuration fraction ([2]). [39] presents the current best measurement of the mid-infrared QLF, but is hampered at high-z by low number statistics, with only ∼100 quasars at $z \geq 3$. Our new deep and wide *Spitzer* survey, SpIES, will observe $\gtrsim$25,000 unobscured and obscured quasars, with $\gtrsim$1,200 at $z \geq 3$.

Science Goal 2: A second science aim will be the measurement of the unobscured QLF, down to $g = 22$ and up to $z \approx 5$. eBOSS and TDSS, both include quasars as a major component, but select them very differently, yielding the largest and most complete spectroscopic survey of quasars ever created. The SDSS-IV quasar samples will match the BOSS quasars in luminosity range, but now at redshifts $z < 2$. *Thus, with SDSS-I/II, SDSS-III BOSS and SDSS-IV:eBOSS+TDSS, the luminosity-redshift* $(L - z)$ *plane for all quasar is fully sampled out to* $z \approx 5$ *for the first time.*

Science Goal 3: Will be to place these new QLF measurements in context of AGN feedback models, including using the prescriptions found in the latest suite of hydrodynamical cosmological simulations, e.g. Illustris ([40]) and EAGLE ([41]).

Project feasibility, Timeline and role of the P.I. Data from SDSS+BOSS+SpIES+WISE are all in-hand and the necessary catalogues will be produce by the end of 2015/early 2016, well timed for the PDRA to start immediately on the SDSS+SpIES+WISE QLF work. A cosmologically interesting dataset from SDSS-IV eBOSS+TDSS will be in hand by mid-2016. The P.I. is actively involved in producing these quasar catalogues, and will support the PDRA in achieving the science goals.

MIQSOs Project 2: The Environments of $z > 3$ Quasars (4 year PhD project)

This project will again leverage the optical and new mid-infrared datasets to make the first clustering measurements of faint $z > 3$ quasars. These results will be directly used to constrain AGN feedback models.

Science Goal 1: Will be to make the first ever measurement of the clustering of the faint $z > 3$ MIR-selected quasar population. [33] contrasts the behaviour of quasar clustering strength for 3 flavours of feedback model as a function of survey depth and redshift, demonstrating that they are degenerate in a survey like SDSS due to a lack of dynamic range in quasar luminosity. However, [33] also note that extending the depth of quasar surveys to $i = 23$ (1-2 mags deeper than BOSS) will move further down the QLF, increasing the quasar density enough to break the degeneracy between models at high-z. This measurement will be possible with the new SpIES dataset.

Science Goal 2: Recent measurements at $z \sim 1.5$ ([42], [43]) have claimed that the obscured quasar population are at least as strongly clustered as the unobscured (optically selected) quasars. This result has dramatic consequences if confirmed, placing tight constraints on the sequence of evolutionary stages for luminous AGN. Using WISE to perform a similar selection to these studies, BOSS has targeted ∼30,000 mid-IR selected objects, a key goal of which is to perform a clustering measurements with *spectroscopic redshifts* (a key limitation to [35], [36]) and to test this intriguing result at high significance and place the quasars in a broader evolutionary context.

Science Goal 3: The eBOSS clustering sample is ≈20× larger than the current best measurement from SDSS in the same redshift range ([30]). This will lead to the first sub-percent constraint on quasar bias at $z \sim 1.5$, or, match SDSS-level constraints in 20 bins of $dz = 0.1$ and measure bias evolution. This dataset, with its range in luminosity at all redshifts will provide the first meaningful clustering constraints on luminosity-dependent quasar clustering and thus quasar fueling [44]. It will also provide a factor of ∼3 improvement in measurement of clustering amplitude in the range $40 < r < 100$ kpc/h, providing the first ∼10% level constraint on fraction of quasars in satellite halos.

Project feasibility, Timeline and role of the PI. Again, the key data are in hand, and will be ready for the PhD student to immediately exploit. The P.I. is the lead on the BOSS+WISE quasar spectroscopic programme. The P.I. has experience in writing clustering code and the relevant data analysis, but the student would be encouraged to further develop the analysis techniques. The P.I would naturally play an active supervisory role in all these research activities.

MIQSOs Project 3: Early Science with *The James Webb Space Telescope* (P.I. Led Project)

The *James Webb Space Telescope* (*JWST*) is a 6.5-meter infrared telescope that will initiate and enable completely transformative science. Due to its collecting area and wavelength coverage, in many ways, *JWST* is not "*Hubble's* successor", but more like a "Super-*Spitzer*" and a "Mega-WISE" combined in one. This project is designed to ramp up to the launch of the *James Webb Space Telescope* and plan for the Early Release Science (ERS) program, a suite of new observations that will become immediately public very early in *JWST* observing.

Science Goal 1: The discovery of the extremely red quasars ([24]) seems to provide a key observational clue to the "major merger" evolutionary theory for quasar activity ([17]). The P.I. is a lead Co-I in a small team of 9 members that is acquiring time on 8-10m class telescopes in order to understand these potentially really important objects. So far we have data from VLT XShooter, and have recently been granted time in 2015A and 2015B on Keck One (LRIS spectropolarimetry), Gemini North (GNIRS spectroscopy) and the LBT (LUCI+MODS optical/NIR spectroscopy). *The P.I. will lead these joint data analyses (and if necessary further follow-up proposals) and the subsequent interpretation, modeling and paper production.*

Science Goal 2: There will be an Early Release Science (ERS) program, that will take maximal advantage of *JWST's* new and uniquely powerful capabilities immediately upon commencing science operations. One natural ERS case for *JWST* is the investigation of obscured and very red quasars, using the MIRI spectrograph, and by utilizing all my experience with mid-infrared datasets, surveys and object discovery, I am positioning myself to carry out these investigations. *A call to the community to define ERS science will be issued later in 2015, and I will become a lead European Investigator and responsible for this revolutionary mission.* The *JWST* is scheduled for launch in late 2018, which due to the project's scheduled reserve is now very feasible. Regardless, the ERS Science case will be written over the course of the ERC 2015 Starter Grant, and even a years delay in launch sees the non-proprietary ERS data delivered before the end of the grant.

I request funding for the full 5 year period for the ERC Starter Grant. This includes support for the P.I. at 100% for 5 years, a PDRA at 100% for 3 years, and a PhD student at 100% for 4 years. I also request 'buy-in' to the SDSS-IV project which allows data rights and collaboration access for the P.I., the PDRA and PhD student. Additional project funds are requested for computing resources and travel for conferences, observing runs and collaboration meetings.

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- **POSITIONS**

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

2013 - 2014 Research Assistant Professor
Drexel University, U.S.A., Advisor: Prof. Gordon T. Richards

2009 - 2013 Postdoctoral Researcher/Project Scientist, Berkeley Cosmology Group
Lawrence Berkeley National Lab, U.S.A., Advisor: Dr. David. J. Schlegel

2007 - 2009 Postdoctoral Research Scholar, Dept. of Astronomy and Astrophysics
Pennsylvania State University, U.S.A., Advisor: Prof. Donald. P. Schneider

- **EDUCATION**

2003 - 2007 Ph.D. in Astrophysics, **University of Durham**, U.K.
"*The Clustering and Evolution of Massive Galaxies*", Advisor: Prof. Tom Shanks

1999 - 2003 M.Sci., Physics & Astronomy, **University of Durham**, U.K.
First Class Honours, Fourth Year Advisor: Prof. Shaun Cole

- **FELLOWSHIPS AND AWARDS**

2014 – 2019 Science & Technology Facilities Council
Ernest Rutherford Fellowship
Senior Research Fellowship, *University of Edinburgh*

- **PUBLICATION RECORD**

Author on 90 published papers	Total number of citations:	6537 (72.6 citations/paper)
First author on 5 published papers	Total number of citations:	383 (76.6 citations/paper)
h-index of 40.		

- **SUPERVISION OF GRADUATE STUDENTS**

2013 - **John Timlin**
Drexel University Graduate Student, Philadelphia PA, USA
(On Ph.D. Dissertation Committee)

2013 - 2014	**Victoria Tielebein** Drexel University Senior Thesis 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

- **TEACHING ACTIVITIES**

2015	Joint Instructor, *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

- **GRANTS/FUNDING OBTAINED**

2014 - 2019	€674,663	STFC Ernest Rutherford Fellowship, P.I.
2012 - 2016	€387,327	NASA *Spitzer Space Telescope*, Cycle 9, Lead Co-I
2012 - 2013	€ 94,025	NASA, *Hubble Space Telescope,* Cycle 20, P.I.
2010 - 2011	€ 45,125	NASA *Chandra* Cycle 12 Co-I archival proposal "The Dark Matter-AGN connection with Weak Lensing"
2008 - 2009	€ 29,953	NASA *Swift* XRT and UVOT observations, Cycle 5, P.I.

- **ORGANISATION OF SCIENTIFIC MEETINGS**

2014	SOC Member, *Multi-wavelength Heritage of Stripe 82 Workshop*, Princeton University
2011	SOC Chair, SDSS-III BOSS Quasar Working Group meeting, Princeton University

- **PROFESSIONAL/MEMBERSHIPS**

Referee for:	*Monthly Notices of the Royal Astronomical Society* *The Astrophysical Journal* *The Astronomical Journal* Fellow Royal Astronomical Society (since July 2004) Full Member American Astronomical Society, (since Nov 2009) Founder "Astronomers for America"

- **MAIN COLLABORATIONS**

Prof. Gordon Richards,	Department of Physics, Drexel University, Philadelphia PA, USA
Prof. Michael Strauss,	Department of Astrophysical Sciences, Princeton University, Princeton NJ, USA
Prof. Donald Schneider,	Dept. of Astronomy & Astrophysics, Penn State University, State College, USA
Dr. David Schlegel,	Lawrence Berkeley National Lab, Berkeley CA, USA
Prof. Martin White,	UC Berkeley, Berkeley CA, USA
Prof. Fred Hamann,	U. Florida, Gainesville FL, USA
Prof. Nadia Zakamska,	Johns Hopkins University, Baltimore MD, USA
Prof. Adam Myers,	University of Wyoming, Laramie WY, USA
Dr. Ian McGreer,	Steward Observatory, University of Arizona, Tuscon AZ, USA
Dr. Isabelle Pâris**,**	Osservatorio astronomico di Trieste, Trieste, Italy.

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

<u>Mandatory information</u> *(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.	674,663	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 not overlapping with ERC proposal. ERC proposal would build-on, and is a novel extension to, the current research programme.

Grant applications

n/a

PUBLICATIONS

Ross, Nicholas P. and 41 co-authors
The SDSS-III Baryon Oscillation Spectroscopic Survey: The Quasar Luminosity Function from Data Release Nine
2013, The Astrophysical Journal, Volume 773, Issue 1, article id. 14, 27 pp.
2013ApJ...773...14R
10.1088/0004-637X/773/1/14
30 citations

Ross, Nicholas P and 38 co-authors
The SDSS-III Baryon Oscillation Spectroscopic Survey: Quasar Target Selection for Data Release Nine
2012, The Astrophysical Journal Supplement, Volume 199, Issue 1, article id. 3, 29 pp.
2012ApJS..199....3R
10.1088/0067-0049/199/1/3
83 citations

Pâris, I.; Petitjean, P.; Aubourg, É.; Bailey, S.; **Ross, Nicholas P.** and 70 co-authors
The Sloan Digital Sky Survey Quasar Catalog: Ninth Data Release
2012, Astronomy & Astrophysics, Volume 548, id.A66, 28 pp.
2012A&A...548A..66P
10.1051/0004-6361/201220142
99 citations

Schneider, Donald P.; Richards, Gordon T.; Hall, Patrick B.; Strauss, Michael A.; Anderson, Scott F.; Boroson, Todd A.; **Ross, Nicholas P.** and 41 co-authors.
The Sloan Digital Sky Survey Quasar Catalog. V. Seventh Data Release
2010, The Astronomical Journal, Vol. 139, Page 2360
2010AJ....139.2360S
DOI: 10.1088/0004-6256/139/6/2360
367 citations

Ross, Nicholas P. and 10 co-authors
Clustering of Low-redshift (z <= 2.2) Quasars from the Sloan Digital Sky Survey
2009, The Astrophysical Journal, Volume 697, Issue 2, pp. 1634-1655
2009ApJ...697.1634R
10.1088/0004-637X/697/2/1634
108 citations

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*

LEADERSHIP

2014 - 2019	P.I., STFC Ernest Rutherford Fellowship
2013 -	Primary Co-I, *Spitzer Space Telescope,* Cycle 9 GO program "SpIES: The Spitzer-IRAC Equatorial Survey"'
2012 -	Scientific P.I., *Hubble Space Telescope,* Cycle 20, 18 orbits awarded "The Host Galaxies of High-Luminosity Obscured Quasars at z~2.5"
2012 -	P.I., "WISE BOSS" SDSS-III Ancillary Program A spectroscopic survey of 30,000 12um selected QSOs
2012 -	Co-I, *Herschel Space Observatory,* OT2 program "HeRS: The *Herschel* Redshift Survey"
2011	Chapter Editor, *BigBOSS* NOAO Proposal http://arxiv.org/abs/1106.1706v1
2011 -	P.I. (shared) "VICS82: The VISTA-CFHT Stripe82" Survey
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

RECENT SELECTED PRESENTATIONS

2014 September	Princeton University	CosmoLunch talk
2014 May	Harvard University	HEAD talk
2014 May	Penn State University	Lunch talk
2014 April	Drexel University	Physics Colloquium
2014 April	University of Pennsylvania	Astrophysics Seminar
2014 March	Princeton University	Invited talk, "Heritage of Stripe 82" meeting
2013 November	University of Florida	Colloquium
2013 July	Durham University	"Ripples in the Cosmos" conference
2013 May	Stanford University	KIPAC Tea Talk
2013 January	University of Washington	Colloquium
2012 July	Durham University	ICC, Seminar
2012 April	UC, Irvine	Seminar
2012 April	Trieste, Italy	"Interacting Galaxies and Binary Quasars"
2012 April	University of Edinburgh	Coffee Talk
2012 January	New York University	Plenary Talk, BOSS Collaboration meeting
2011 November	UC, Santa Cruz	FLASH Seminar
2011 July	Oxford University	BICAP Cosmology Seminar
2011 May	Yale University	YCAA Seminar
2011 May	Lawrence Berkeley Lab	INPA Journal Club Meeting
2010 October	IMPU, Tokyo	Galaxies and AGN Workshop
2010 September	Cambridge University	IoA Seminar

MIQSOs: Connecting Quasars with galaxy formation via Mid-IR observations and Next Generation Telescopes

In the local Universe, there is a link between the key properties of massive galaxies, such as bulge mass, and their central supermassive black holes. This has led to the proposal that the supermassive black hole, when accreting, has an influence on its host galaxy by the means of some regulatory "feedback" mechanism(s). However, the details of the physical processes involved in active galactic nuclei (AGN) feedback are still disputed and, moreover, direct observational evidence for AGN feedback in the early universe is heavily conspicuous by its absence. As such, a major source of uncertainty in our current understanding of galaxy evolution is how supermassive black holes influence, and potentially regulate, their host galaxies.

The primary aim of this proposal is to elucidate the nature of quasar activity and AGN feedback, particularly at high-redshift. Using new optical and mid-infrared datasets, that the P.I. has unique access to, the accretion history of the Universe at redshifts $z = 2 - 7$ will be established. These measurements will constrain the energetics of black hole mass build-up, will test feedback models at high-z and lead to a deeper understanding of the physical processes involved in galaxy formation and evolution.

1 Introduction

The two key sources of energy in a galaxy are nuclear fusion in stars, and the energy liberated in a strong gravitational field, e.g. by accretion onto a supermassive black hole (SMBH). The rate of stellar and gravitational energy production are observed to have evolved in a similar fashion, with both the star-formation rate density and luminous AGN i.e., quasar[1] activity peaking around 3 Gyr after the Big Bang at $z \sim 2$ (Madau & Dickinson, 2014; Ross et al. 2013).

The link between massive galaxies and the central SMBHs that seem ubiquitous in them is now thought to be vital to the understanding of galaxy formation and evolution (e.g., Fabian 2012; Alexander & Hickox 2012; Heckman & Best, 2014). Quasars, i.e., luminous active galactic nuclei (AGN) were initially thought to be mere cosmic oddities due to their extreme energetics and rarity. However, several lines of evidence (Soltan 1982; Yu & Tremaine 2002; Bell 2008; Shankar et al. 2009) suggest that *every massive galaxy went through a luminous AGN phase*, and AGN activity is now presumed to be an intimate part of galaxy formation and evolution.

The lines of evidence, both observational (**O**) and theoretical (**T**) that link AGN to the co-evolution of galaxies, include, but are not limited to:

1. Every local massive galaxy with a bulge hosts a supermassive black hole (**O**; e.g., Bell 2008);
2. There is a tight correlation, a scaling relation, between BH mass ($M_{\rm BH}$) and the velocity dispersion σ of the bulge component of the host galaxy (**O**; Richstone et al. 1998, Magorrian et al. 1998, Ferrarese et al. 2000, Gebhardt et al. 2000, Tremaine et al. 2002, Gültekin et al. 2009);
3. The evolutionary trend of 'cosmic downsizing' in AGN and galaxies is generally the same, with stellar activity moving to smaller mass and galactic nuclear activity moving to less luminous systems as redshift decreases (**O**; Madau & Dickinson 2014, Brandt & Alexander 2015);
4. The scaling relations and AGN downsizing then suggest a self-regulation, or "feedback" system to prevent runaway BH growth, and the overproduction of very massive galaxies with young stars (**T**; e.g., Springel et al., 2005, Bower et al. 2006, Croton et al. 2006);
5. There is ample energy available to drive quasar 'winds' and gas outflows as a feedback mechanism, that would impact on the host galaxy and the surrounding environment (**O** & **T**; see e.g. Zakamska & Greene 2014 and references therein).

[1] The terms 'QSO', 'quasar' and 'luminous AGN' are all used interchangeably in this proposal to mean an object radiating at $\gtrsim 10^{38}$ Watts in bolometric luminosity, powered by accretion of material onto a supermassive black.

Consequently, the co-evolution of galaxies and AGN is a crucial ingredient in, and test of, modern theories of galaxy formation. The energy feedback from AGN is thought to impact their host galaxies, and thus influence their present-day properties (e.g., Cattaneo et al. 2009, Fabian, 2012). Observations of the evolution of quasar properties over cosmic time can inform such models and therefore our understanding of the galaxy-black hole connection. Thus, having access to the high-z Universe via quasar demographics, gives insight to galaxy formation and evolution at these early epochs.

Subsequently, a central question in current extragalactic astrophysics is to understand the global demographics, and hence the physical processes involved in luminous AGN activity and the influences on the host galaxy and environment (Kormendy & Ho 2013). As such, huge observational and theoretical effort has been invested in trying to measure and understand the physics involved in these enigmatic systems.

1.1 A full census of the Quasar Population

A pillar of our current understanding of the buildup of SMBHs over cosmic time is the "Sołtan argument" (Soltan 1982) which relates the integrated quasar luminosity density to the mass density of relic black holes in the local Universe. However, it is *crucial* that this census of quasar emission includes contributions from obscured quasars, which are accreting SMBHs where gas and dust block our line-of-sight to the central engine. This obscuration could arise from a torus (e.g., Antonucci 1993, Urry & Padovani, 1995) with unobscured and obscured quasars representing different viewing angles, or, represent different phases of quasar evolution (Sanders et al. 1988, Canalizo et al., 2001, Hopkins et al., 2006) with all quasars passing through an obscured phase before outflows expel the obscuring material. Observationally, obscured AGN are *at least as common* as unobscured AGN in the local Universe. If quasars at high-z are similarly obscured, our understanding of SMBH growth needs to be substantially revised.

Critically, new estimates of the local black hole mass density (Kormendy & Ho, 2013; Graham & Scott 2013, 2015) suggest it is up to $\sim$5 times higher than previously determined, which requires a corresponding increase in the amount of accretion. This can be explained by either super-Eddington accretion (Novak 2013) and/or a population of heavily obscured AGN (Comastri et al, 2015). Thus accounting for this "missing accretion", and the energetics associated with it, is an outstanding issue and a key ingredient required for any AGN feedback model.

Furthermore, I am currently leading the investigations into a new class of object, the "extremely red quasars" that have optical spectroscopy from SDSS/BOSS, and $r - [22\mu\mathrm{m}] > 14$ colours (i.e., $F_\nu(22\mu\mathrm{m})/F_\nu(r) \gtrsim 1000$) from the Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010, Ross et al. 2014) satellite. The physical nature of these objects is currently uncertain, but new infrared spectroscopy shows these objects may have interesting gas kinematics and very strong outflows, suggesting this is a "transition population", with the quasar 'breaking out' of its obscured phase.

Due to the dust reprocessing of UV/optical photons from an active AGN, mid-infrared observations are the key to identifying even the most heavily obscured quasars (Lacy et al., 2004; Stern et al., 2005; Martinez-Sansigre et al. 2006; Alexander et al., 2008 Richards et al. 2009; Donley et al. 2012; Richards et al., 2015). Thus, the combination of optical spectroscopy and mid-IR photometry over large areas of the sky is ideally suited to detecting high-redshift luminous AGN as well as highly obscured AGN, ready to complete the AGN census.

1.2 AGN Feedback at High-z

Modern galaxy formation theory strongly suggests that the active, i.e., quasar, phase of black hole activity has a controlling effect on shaping the global properties of the host galaxies. As such, "AGN feedback" (kinetic and radiative energy impacting galaxy-scale gas/dust) is one of the hottest topics in galaxy evolution today and has become a routinely invoked ingredient for galaxy formation models. The period around $z \sim 2.5$ is particularly important for quasar feedback studies because it marks the peak of both star formation and quasar activity in the universe, and thus high-z, luminous (obscured) quasars are the most likely sites where powerful feedback takes place. This feedback can drive strong winds that clear the galaxy of gas, shutting-off star formation (e.g., Hopkins et al. 2006, 2008). However, direct observations of quasars exhibiting outflows in situ are challenging and lacking (especially at high redshift), and the physical details of these processes are poorly known.

There is however, another avenue that can bring insight, and that is the demographic study of the environments of the QSOs i.e., via a measure of their clustering. Different AGN feedback models (e.g., Hopkins et al. 2007) predict similar clustering at $z < 2$ where observations indicate that quasars with a range of BH masses and accretion rates must be hosted by similar, moderately massive structures (Croom et al. 2005; da Angela et al. 2008; Ross et al. 2009, Shen et al. 2009). However, the feedback models diverge at higher redshift since quasars with lower BH masses and/or accretion rates are not expected to inhabit the extremely massive structures occupied by SDSS quasars (which represent the most massive $z > 3$ BHs accreting at Eddington; Shen et al. 2007). To break this degeneracy we must probe fainter than L^* at beyond $z = 3$.

1.3 This Research Proposal

This proposal aims to address the following key questions:

1. Do we have a complete census of the accreting quasar population across the redshift range $z = 2 - 7$?
2. How much accretion and black hole mass build up occurs in the obscured phase, and how does this influence the host galaxy?
3. At $z > 2$, what environments are obscured and unobscured quasars found in?
4. Are the "Extremely Red Quasars" an important transition population?

2 Methodology I: Measurements

2.1 The Quasar Luminosity Function

The bolometric Quasar Luminosity Function (QLF) is a fundamental observable of the quasar population and links actively accreting supermassive black holes to the environments and evolution of their host galaxies. Using data from the SDSS-III BOSS, new wide-field *Spitzer* surveys and the Wide-field Infrared Survey (WISE) mission, we will make a new measurement of the bolometric QLF concentrating on redshifts $z > 3$ which are currently ill constrained. This new measurement will have immediate and wide-ranging implications including differentiating power between AGN fueling modes at high-z, reionization studies, and predictions for expected yields of very high-z quasars from new missions and telescopes (see e.g. Hopkins, Richards & Hernquist, 2007).

A vital observable of the quasar phenomenon is the number density of quasars as a function of luminosity; the quasar luminosity function (QLF). The cosmological evolution of the quasar luminosity function has been of interest since quasars were first identified over half a century ago and measuring the QLF, and its evolution with redshift, is important for several reasons. It is generally believed that present-day supermassive black holes (SMBHs) gained most of their mass via gas accretion during an active nuclear phase, potentially at quasar luminosities ($L_{\rm Bol} \gtrsim 10^{45}$ erg s^{-1}; Salpeter 1964, Zel'dovich & Novikov 1965; Lynden-Bell 1969, Soltan 1982), so an accurate description of the QLF allows us to place constraints on the formation history of supermassive black holes (e.g., Rees 1984; Madau & Rees 2001; Volonteri & Rees 2006; Netzer & Trakhtenbrot 2007; Haiman 2013) and to map the black hole accretion history of the Universe via the black hole mass function (Shankar et al. 2009, 2010; Shen 2009, Shen & Kelly 2012), as well as constrain the effect of black hole spin on the central engine (Volonteri et al. 2005; Fanidakis et al. 2011,2013; Novak 2013).

Measurements of the QLF also place constraints on the intensities and nature of various cosmic backgrounds, including the buildup of the cosmic X-ray (Shanks et al. 1991; Comastri et al 1995; Ueda et al. 2003; Brandt et al. 2005; Hickox et al. 2006), ultraviolet (UV; Henry 1991) and infrared (IR; Hauser & Dwek 2001, Dole 2006) backgrounds. Knowledge of the UV background is relevant for calculations that involve the contribution of quasar UV photons to the epoch of H reionization (see Fan et al. 2006 for a review) at $z \gtrsim 6$. At lower ($z \lesssim 6$) redshift, quasars contribute towards a fraction of the ionizing photons that keep most of the H ionized, allowing investigations of the Ly-α forest (LyαF; e.g., Lynds 1971; Meiksin 2009; Busca et al. 2013; Slosar et al. 2013; Delubac et al. 2015).

Recent large quasar surveys have allowed us to study the properties of the quasar population with unprecedented statistical precision. The number of known quasars has increased nearly 100-fold since the late 1990s, (for photometrically identified quasars, see Richards et al. 2009a) and since that time, there has been a large effort to measure the QLF in the UV/optical (Boyle et al. 2000; Fan et al. 2001, 2004, 2006; Wolf et al. 2003; Hunt et al. 2004; Croom et al. 2004, 2009a; Hao et al. 2005; Richards et al. 2005, 2006b; Jiang et al. 2006; Fontanot et al. 2007; Bongiorno et al. 2007; Reyes et al. 2008; Jiang et al. 2008, 2009; Glikman et al. 2010, 2011; Willott et al. 2010; Ikeda et al. 2011, 2012; Masters et al. 2012 Palanque-Delabrouille et al., 2013; Ross et al. 2013, McGreer et al. 2013), mid-infrared (Brown et al. 2006; Siana et al. 2008; Assef et al. 2011) and the soft and hard X-ray (Cowie et al. 2003; Ueda et al. 2003, Hasinger et al. 2005; Barger et al. 2005; Silverman et al. 2005; Silverman et al. 2008; Aird et al. 2008; Treister et al. 2009; Aird et al. 2010; Fiore et al. 2012, Buchner et al., 2015, Georgakakis et al. 2015).

Quasar number density evolves strongly with redshift (Schmidt 1970; Osmer 1982; Schmidt et al. 1995; Fan et al. 2001b; Richards et al. 2006b; Croom et al. 2009b; Ross et al. 2013; McGreer et al. 2013), and one of the key goals of quasar studies is to understand what drives this strong evolution. *However, a vital caveat here is that the evolution of the optical QLF is a composite of intrinsic quasar evolution and the evolution of the obscuring medium in quasar hosts.*

The QLF is often described by a double power-law (Boyle et al. 2000; Croom et al. 2004; Richards et al. 2006b) of the form

$$\Phi(L, z) = \frac{\phi_*^{(L)}}{(L/L^*)^{\alpha} + (L/L^*)^{\beta}} \tag{1}$$

with a characteristic, or 'break luminosity', L_*, α characterizing the faint-end slope (with values of $\alpha \sim -1.5$) and β characterizing the bright-end slope (and having values of $\beta \sim -3$). Evolution of the QLF can be encoded in the redshift dependence of the break luminosity/magnitude, normalization ϕ_*, and also potentially in the evolution of the power-law slopes.

This functional form has four basic parameters (α, β, ϕ^*, M^*) and various phenomenological models have been proposed to describe how those parameters evolve with redshift. In *Pure Luminosity Evolution (PLE)*, only the break magnitude/luminosity evolves, leaving the overall number density constant. The opposite occurs in *Pure Density Evolution*: the shape of the QLF remains constant while the number density evolves. Various hybrid models allow both to vary but hold the bright- and faint-end slopes fixed. In Luminosity Evolution and Density Evolution (LEDE), $M^*(z)$ and $\Phi^*(z)$ evolve independently, while in Luminosity Dependent Density Evolution (LDDE), the evolution of $\Phi^*(z)$ is related to that of $M^*(z)$. Finally, extensions to these models allow the power law slopes to evolve as well. *Crucially, a PLE model, with no evolution in the power-law slopes, will not give rise to 'AGN Downsizing" — the trend of number density of fainter AGN peaking at lower-redshift than the luminous AGN.*

As the QLF is observed to have a broken power-law form, it is necessary to probe below the luminosity at which the power-law breaks in order to distinguish *luminosity evolution* (where the luminosity of AGN changes with time, but their number density remains constant) from *density evolution* (where the number density of AGN changes, but the luminosities of individual objects remains constant), or a combination of the two. X-ray studies (e.g, Aird et al. 2010; Ueda et al. 2014; Buchner et al. 2015) and some optical, and IR measurements (e.g., Croom et al. 2009a; Assef et al. 2011) indicate that the space density of lower luminosity AGN peaks at redshifts lower than that of bright quasars, specifically observing a flattening of the QLF faint-end slope with redshift. It has been argued that this follows a similar pattern of 'cosmic downsizing' as has been observed in galaxy spheroid populations (e.g., Cowie et al. 1996; Madau et al. 1998; Steidel et al. 1999).

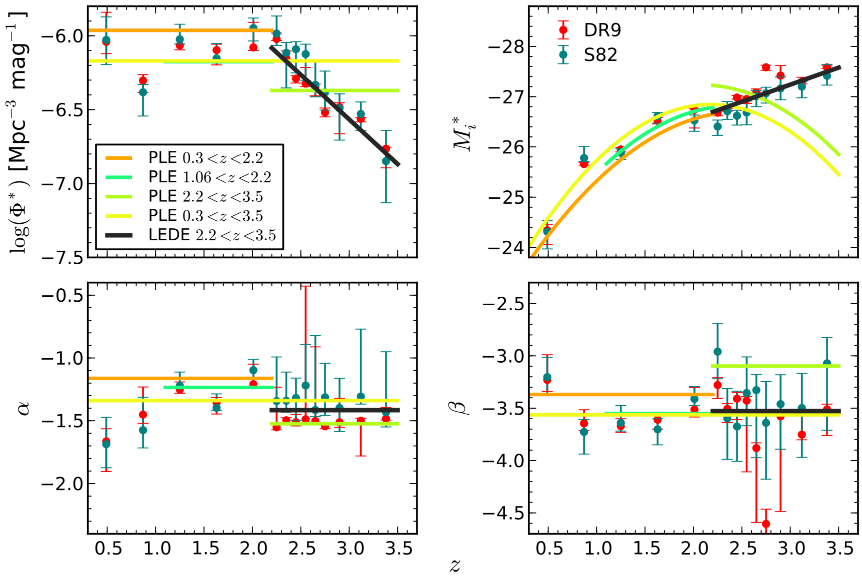


Figure 1: The best-fit values for the parameters Φ^*, M^*, α and β as a function of redshift for the SDSS-III BOSS DR9 Quasar Luminosity Function from Ross et al. (2013). The red points are from the DR9 optical colour-selected sample (Paris et al. 2012), while the teal points are for the variability selected Stripe 82 data, (Palanque-Delabrouille et al. 2012). The four coloured lines represent the four best fitting PLE models from Table 8 in (Ross et al. 2013) over the respective redshift ranges, while the solid black line is the log-linear LEDE model.

2.1.1 Current State of the Art

The Optical QLF at $z \leq 2.5$: At $z \leq 2.5$ (where the "UV Excess" colour selection technique is most efficient), the current state of the art measurements are from Croom et al., (2009b) using the combination of the 2dF-SDSS LRG And QSO survey (2SLAQ; Croom et al. 2009a), which probes down to a magnitude limit of $g = 21.85$, and the brighter ($i = 19.1$) SDSS-I/II Quasar survey (Richards et al. 2002; Schneider et al. 2010). Here, the double power-law form with pure luminosity evolution provides a reasonable fit to the observed QLF from low-z up to $z \simeq 2$, but it appears to break down at higher redshift. However, the 2SLAQ sample has few objects above $z \sim 2$, and SDSS does not probe below L_* at higher redshifts, making it difficult to constrain the faint end of the QLF at high-z.

Optical QLF at $z \gtrsim 2.5$: At $z \gtrsim 2.5$, the constraints on the QLF are less clear-cut, as the selection of luminous quasars becomes less efficient. This situation arises because the broad-band colours of $z \approx 2.7$ and $z \approx 3.5$ quasars are very similar to those of A and F stars (Fan 1999; Fan et al. 2001b; Richards et al. 2002; Ross et al. 2012) in the Sloan Digital Sky Survey colour system (Fukugita et al. 1996). Although there is good constraining power at the bright end at $z > 2$, (e.g., Richards et al. 2006b; Jiang et al. 2009), using just SDSS there is uncertainty in the form, and evolution of the QLF at $z > 2$, especially at the faint end. The redshift range $z \sim 2-3$ is of particular importance since the luminous quasar number density peaks here; this is often referred to as the "quasar epoch" (Osmcer 1982; Warren et al. 1994; Schmidt et al. 1995; Fan et al. 2001b; Richards et al., 2006b; Croom et al. 2009b).

Using data from the SDSS-III BOSS, Ross et al. (2013), along with Palanque-Delabrouille et al. (2013), and McGreer et al. (2013) measured the optical QLF at $z = 2-4$ and $z \approx 5$, respectively. In particular, Ross et al. (2013; Figure 1), measured the break luminosity L^* in the double-power law form of the $2 < z < 4$ QLF for the first time. This is important since the majority of black hole mass build-up happens for AGN at the break luminosity, and this epoch is where quasar activity peaks. Ross et al (2013) showed that 'pure luminosity evolution' is still an adequate description of the QLF at $z \lesssim 2$ - only changing to a 'luminosity dependent' density evolution at $z \gtrsim 2$. What drives this evolution, the directly related fueling mechanism (e.g., mergers vs. secular processes) and the feedback physics invoked, are key outstanding issues and will be tackled by this proposal.

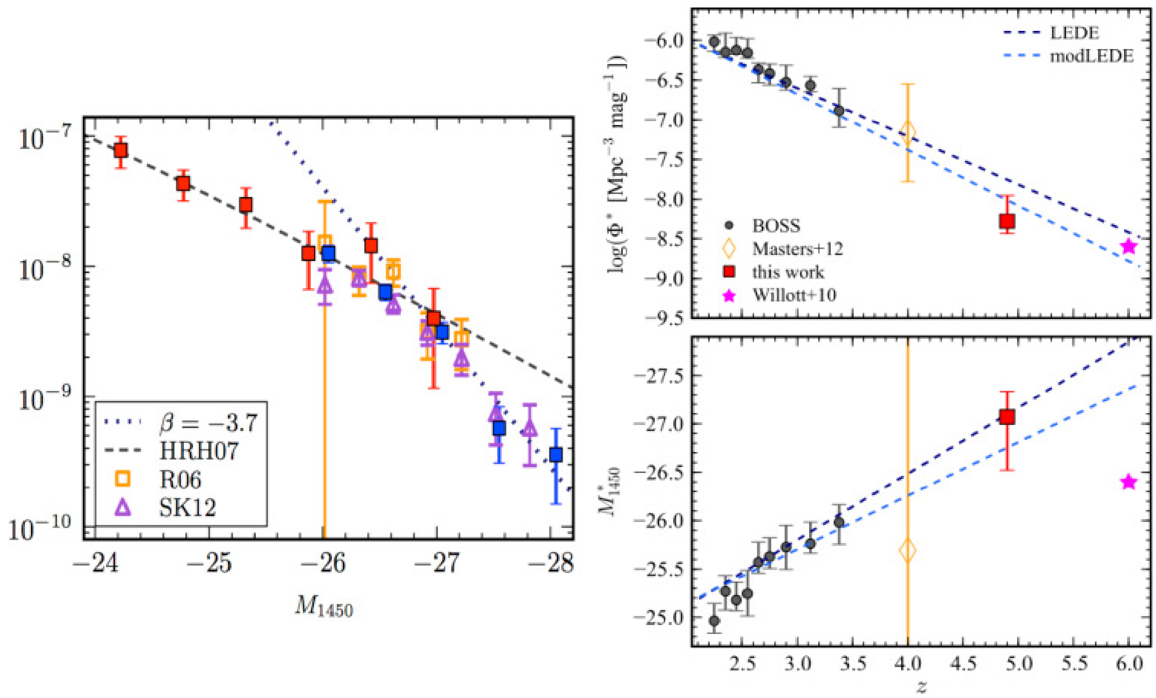


Figure 2: *(Left:)* The new QLF measurement at $z \sim 5$ from McGreer et al. (2013) using SDSS (blue) and Stripe 82 (red) data. The dotted line shows a single power law fit to points with $M_{1450\text{Å}} < -27$ ($\beta = -3.7$). The departure from a single power law is evident when the faint Stripe 82 data are included. For comparison, previous calculations are given by the orange points for the SDSS DR3 from Richards et al. (2006b), using an area of 1622 deg^2, while the purple points show the SDSS DR7 calculation from Shen & Kelly (2012) covering 6200 deg^2. The dashed lines correspond to the Hopkins, Richards, & Hernquist (2007) model, where most of the constraint comes from the Richards et al. (2006b) points. *(Right:)* Evolution of the QLF normalization (Φ^*) and break luminosity (M^*_{1450}) between $z \sim 2$ and $z \sim 6$. The points at $2.2 < z < 3.5$ come from the BOSS DR9 QLF (Ross et al. 2013). The point at $z = 4.9$ is from the best-fit model in (McGreer et al. 2013). The point at $z = 4$ is from (Masters et al. 2012) and the one at $z = 6$ is from Willott et al. (2010), using their $\alpha = -1.8$ fit (uncertainties for the parameters were not reported for this fit). A log-linear LEDE model fit to the BOSS data is shown as a dark blue dashed line, and a modified form (shown as a light blue dashed line) of this model is discussed in McGreer et al. (2013).

Similarly, the bright-end slope of the QLF has been argued to become shallower towards higher redshifts (e.g., Fan et al. 2001b; Fan et al. 2003; Richards et al. 2006b), but new evidence (e.g. McGreer et al., 2013, Figure 2) suggest this is not the case. The combination of the new BOSS results puts the Hopkins, Richards & Hernquist (2007) result in serious doubt, see Figure 3.

The MIR QLF: Assef et al. (2011) present the J-band luminosity function of 1838 mid-infrared and X-ray-selected AGN in the redshift range $0 < z < 5.85$, though crucially, this sample only has ~ 100 AGN with $z > 3$. Very recently, Lacy et al. (2015) presented luminosity functions derived from a spectroscopic survey of AGN selected from *Spitzer Space Telescope* imaging surveys. However, this study is also very much limited to $z \lesssim 1.5$ since gaining optical spectroscopy for a complete sample of obscured and optically faint AGN at high-z is difficult. In a similar manner to Ross et al. (2014), who identified the "extremely red quasar" population, Assef et al. (2014) perform a selection using the WISE $W4$ 22μm band. This selects objects that not only may have heavily buried and obscured AGN, but also that might be heavily star-forming.

How the traditional IR AGN selection (e.g. Lacy et al. 2004; Stern et al. 2005, Richards et al. 2009, 2015) overlaps and complements with the W4 22μm selection is currently unclear, and it will be the combination of these two selections from Spitzer+WISE that will fulfill the criteria to create the full Quasar census.

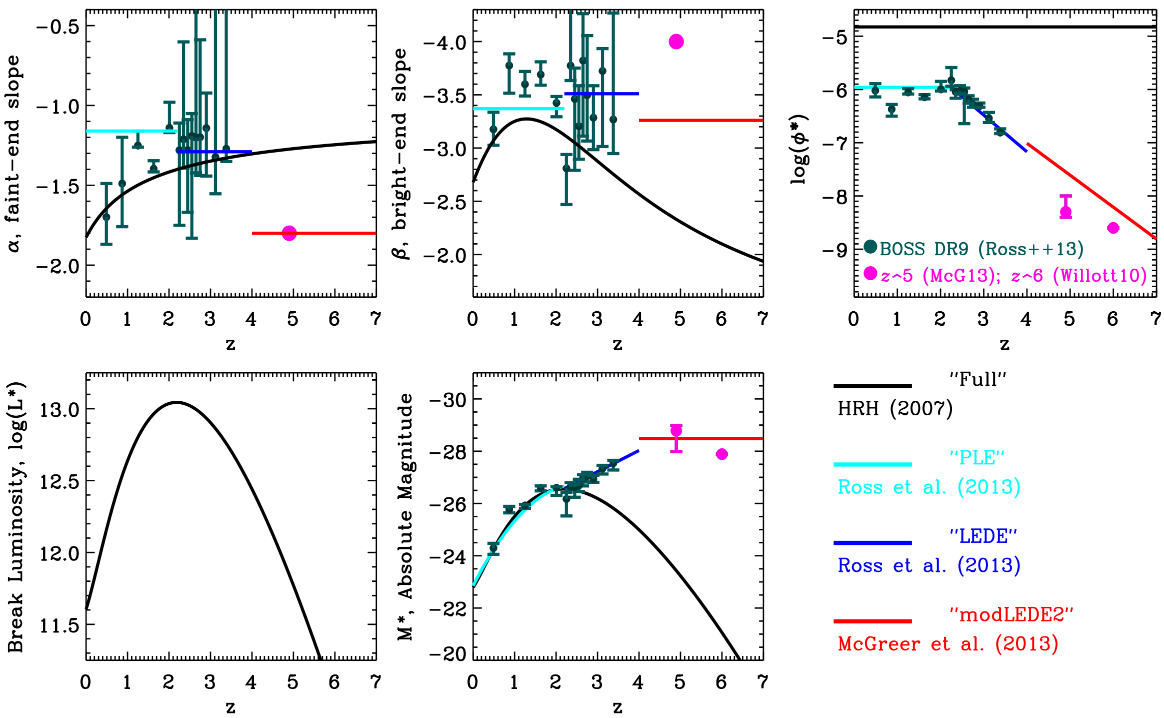


Figure 3: After Fig. 8 of (HRH07), and the evolution of the four key parameters of the QLF: α, the faint-end slope (top left); β, the bright-end slope (top center); ϕ^*, the normalization (top right) and M^*, the break magnitude (bottom center). Also shown is the break luminosity in L* (bottom left). The best-fit "Full" model from HRH07 is given by the black curves, whereas the best-fit PLE and LEDE models from (Ross et al. 2013) are given by the light and dark blue lines, respectively. The second version of the modified LEDE model reported in McGreer et al. (2013) is the red line, and the disagreement between HRH07 and the new data/models is stark.

2.2 Clustering and the 2-Point Correlation Function

Understanding how and when the structures in the local Universe formed from the initial conditions present in the early Universe is one of the fundamental goals of modern observational cosmology. Tracing the evolution of clustering with cosmic epoch offers the potential to understand the growth of structure and its relation to the energy and matter content of the Universe, including the relationship between the dark matter and the luminous galaxies and quasars that we observe.

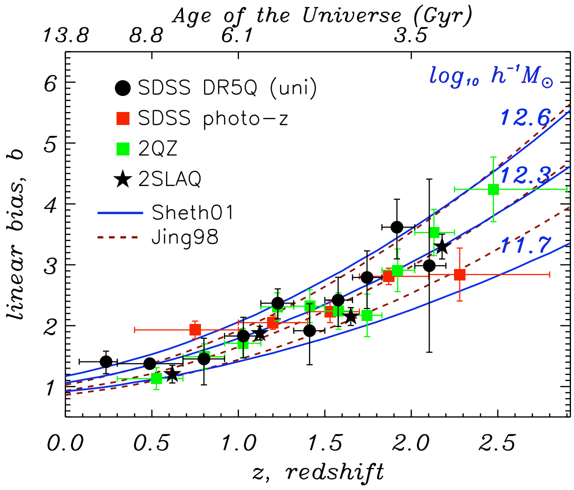
The two-point correlation function (2PCF), ξ, is a simple but powerful statistic commonly employed to quantify the clustering properties of a given class of object (Peebles et al. 1980). The observed value of ξ for quasars can be related to the underlying (dark) matter density distribution via

$$\xi(r)_{\rm quasar} = b_Q^2 \; \xi(r)_{\rm matter} \tag{2}$$

where $\xi(r)_{\rm matter}$ is the mass correlation function and b_Q is the linear bias parameter for quasars.

With certain reasonable assumptions, the measurement and interpretation of the bias can lead to determination of the dark matter halo properties of quasars and to quasar lifetimes (t_q; Martini 2001, Haiman 2001). In the standard scenario, quasar activity is triggered by accretion onto a central, supermassive black hole (SMBH; e.g., Salpeter 1964; Lynden-Bell 1969, Rees 1984). Given the possible connection between the SMBH and host halo, and the fact that halo properties are correlated with the local density contrast, clustering measurements can be used to constrain this potential halo-SMBH connection and provide an insight into quasar and black hole physics (e.g., Baes et al. 2003; Wyithe & Loeb 2005; Adelberger et al. 2005; Wyithe & Padmanabhan 2006; Fine et al. 2006; daAngela et al. 2008; Croton 2009; Conroy & White 2013). This information, combined with the quasar luminosity function (QLF), constrains η, the fraction of the Eddington luminosity at which quasars shine, and their duty cycle (Wyithe & Loeb 2005; Shankar et al. 2007; White et al. 2012).

Fig. 4: Evolution of the linear bias of quasars, b_Q, with redshift, to $z = 3$. The (black) circles, are from the SDSS DR5 Quasar sample (Ross et al. 2009); the (red) squares, from the photometric SDSS quasar measurements (Myers et al. 2006); the (green) squares from the 2QZ survey (Croom et al, 2005); the (black) stars are from the 2SLAQ QSO survey (da Angela et al 2008); The solid lines give dark halo masses from the models of Sheth et al. (2001) with $\log h^{-1} M_{\odot} = 12.6$, 12.3 and 11.7 from top to bottom. The dotted lines give dark halo masses from the models of Jing (1998) with $\log h^{-1} M_{\odot} = 12.3$, 12.0 and 11.7 from top to bottom.



2.2.1 Current State of the Art

Using the SDSS, Shen et al. (2007) found that redshift $2.9 \leq z \leq 5.4$ quasars are significantly more clustered than their $z \sim 1.5$ counterparts, having a real-space correlation length and power-law slope of $r_0 = 15.2 \pm 2.7$ h^{-1} Mpc and $\gamma = 2.0 \pm 0.3$, respectively, over the scales 4 h^{-1} Mpc $\leq r_p \leq$ 150 h^{-1} Mpc (where r_p is the separation from the projected correlation function, $w_p(\sigma)$). Shen et al. (2007) also found that bias increases with redshift, with, $b_Q \sim 8$ at $z = 3.0$ and $b_Q \sim 16$ at $z = 4.5$. *Critically, however, since the Shen et al. (2007) measurement is from the SDSS, only quasars at the very bright end of the QLF are sampled at these redshifts. Thus, these measurements alone are unable to differentiate between various AGN feedback models in e.g., Hopkins et al. (2007).*

Porciani et al. (2004), Croom et al. (2005), Myers et al. (2006, 2007a,b) and Ross et al. (2009) have all measured the evolution of clustering for luminous AGN up to $z \sim 2.5$ (see Figure 4) and recently, Krolewski & Eisenstein (2015) measured the luminosity and virial black hole mass dependence of quasar-galaxy clustering at $z \sim 0.8$, finding no appreciable increase in clustering amplitude with quasar luminosity or black hole mass at these low redshifts.

White et al. (2012) and Eftekharzadeh et al. (2015) measure the real- and redshift-space two-point clustering of the BOSS quasar sample. In particular, Eftekharzadeh et al. (2015) use the final quasar sample of the BOSS, with spectroscopic redshifts in the range $2.2 \leq z \leq 2.8$, and which cover over 6800 deg^2 and a comoving volume of $\sim 25\,(h^{-1}\mathrm{Gpc})^3$ and measure the redshift-space correlation function on scales of $3 \lesssim s \lesssim 27$ h^{-1}Mpc. These authors deduce a bias factor of $b_Q = 3.40 \pm 0.27$ which corresponds to a characteristic host halo mass of $\sim 2 \times 10^{12}$ $h^{-1} M_{\odot}$ with a duty cycle for the quasar activity of 1 percent. This sample is also spilt into three luminosity subsamples but again no strong evidence is found for quasar clustering amplitude dependence on luminosity.

Hickox et al. (2009) explore the connection between different classes of AGN and the evolution of their host galaxies, by deriving host galaxy properties, clustering, and Eddington ratios of AGNs selected in the radio, X-ray, and infrared (IR) wavebands. They study a sample of 585 AGNs at $0.25 < z < 0.8$ using redshifts from the AGN and Galaxy Evolution Survey (AGES; Kochanek et al. 2012). Hickox et al. (2009) interpret their results in terms of a simple model of AGN and galaxy evolution, whereby a "quasar" phase and the growth of the stellar bulge occurs when a galaxy's dark matter halo reaches a critical mass between $\sim 10^{12}$ and 10^{13} $M_{\odot}$. After this event, star formation ceases and AGN accretion shifts from radiatively efficient (optical- and IR-bright) to radiatively inefficient (optically faint, radio-bright) modes.

Geach et al. (2013), Donoso et al. (2014) and DiPompeo et al. (2015) all measure the clustering of unobscured and obscured using a WISE W1/W2 colour selection. Controversially, Geach et al. (2013) find a similar clustering strength between the obscured and unobscured quasars, whereas Donoso et al. (2014) and DiPompeo et al. (2015) find that *obscured objects are more clustered than unobscured objects*, suggesting that obscured AGNs inhabit denser environments than unobscured AGNs. If this latter claim is true, they are difficult to reconcile with the simplest AGN 'unification' models,

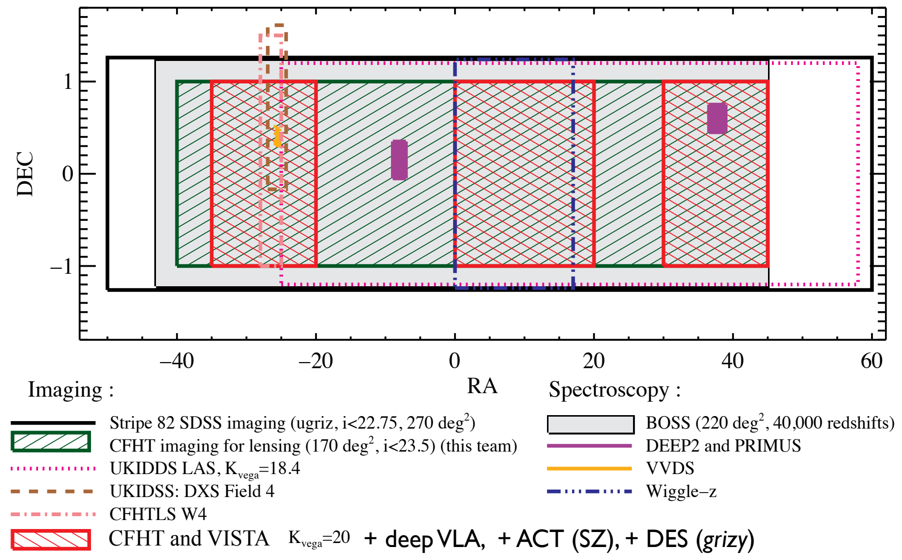


Figure 5: The SDSS Stripe 82 field. SDSS, SDSS-III BOSS, Spitzer (SpIES) and WISE with coverage from the far and near UV (GALEX) through to the near-infrared (NIR; UKIDSS LAS, VISTA VHS) as well as new, deeper data from CFHT-WIRCam and VISTA). Deep radio 20cm radio and ACT-SZ data also currently exist, and coverage in the submm by *Herschel* and the X-rays from XMM-Newton is forth-coming. Spectroscopy is available from SDSS, SDSS-III: BOSS , DEEP2, VVDS, WiggleZ, AUS and the PRIMUS surveys.

where obscuration is driven solely by orientation. *However, all these measurements are done with a cross-correlation technique, and moreover, do not have spectroscopic redshifts to determine the redshift distributions of the quasar samples.*

3 Methodology II: Datasets

3.1 Observational Resources and Complementarity

Key observational resources in AGN detection are: (1) wide-field, multi-band optical quasar surveys such as the Sloan Digital Sky Survey (SDSS; York et al. 2000), the SDSS-III (Eisenstein et al. 2011) and the current incarnation SDSS-IV; (2) deep X-ray surveys (see e.g., Brandt & Alexander 2015 for a recent review) and (3) mid-infrared observations from e.g., the *Spitzer Space Telescope* (Werner et al. 2004) and the Wide-field Infrared Survey (WISE) Explorer Mission (Wright et al. 2010). The complementary nature of these observations is discussed below.

3.2 Wide-field Optical Surveys

The current state-of-the-art in optical quasar surveys is the SDSS (York et al. 2000; Gunn et al. 2006; Abazajian et al. 2009) and the SDSS-III Baryon Oscillation Spectroscopic Survey (BOSS; Ahn et al. 2012, Dawson et al. 2013). SDSS has provided moderate depth optical imaging for 14,500 deg^2 of sky and spectra for nearly 2.5 million galaxies and 400,000 quasars (Alam et al. 2015).

Quasars are identified in 5-band (*ugriz*) optical photometry and are targeted down to $i \leq 19.1$ at $z \lesssim 3$ and $i \leq 20.2$ for $z \gtrsim 3$ in SDSS (Richards et al. 2002), while BOSS concentrates on redshifts $z \approx 2-4$, targeting to $g \approx 22$ (Ross et al. 2002). From the the final SDSS quasar catalogue (Data Release Seven, DR7Q; Schneider et al. 2010), and the new BOSS Data Release Twelve catalogue (DR12Q; Pâris et al. 2015), *the SDSS and BOSS together have a powerful database of 400,000 spectroscopically confirmed quasars waiting to be fully exploited.*

The ~300 deg^2 region along the celestial equator in the Southern Galactic Cap, commonly referred to as "SDSS Stripe 82", is becoming the first field with $> 100\,\text{deg}^2$ of formidable — and continually growing — multi-wavelength, and multi-epoch data, see Figure 5. Stripe 82 was repeatedly scanned over the first five years of SDSS, and then scanned at a higher frequency as part of the hunt for Type Ia supernovae. Thus, there is SDSS *ugriz* coverage, reaching to two magnitudes deeper than single-epoch SDSS imaging. The repeat imaging of this field, with over 80 epochs covering 10 years, makes Stripe 82 a unique laboratory to perform both variability-based selections (Palanque-Delabrouille et al. 2012) as well as deeper optical quasar selections, and have a multi-wavelength dataset over a wide enough field for rare object (i.e. luminous quasar) studies.

3.2.1 SDSS-III: BOSS

With the full 10,000 deg^2 of spectroscopy obtained, including the spectra of 300,000 quasars (Pâris et al. 2015), the SDSS-III: Baryon Oscillation Spectroscopic Survey (BOSS) is complete. *Having been head of the BOSS Quasar Working Group, the P.I. has unique access and knowledge of the BOSS Quasar dataset and was the lead investigator in the target selection (Ross et al. 2012) and QLF measurements (Ross et al. 2013).* As such the P.I., is intimately familiar with selection effects in the BOSS data, and has the experience of having previous QLF analysis codes already in hand.

3.2.2 SDSS-IV

The current 2.5m Sloan telescope and BOSS spectrograph system will remain state-of-the-art for at least for the mid-term. As such, the immediate future of spectroscopic surveys is the fourth installment of the Sloan Digital Sky Survey, SDSS-IV.

SDSS-IV: eBOSS: The Extended Baryon Oscillation Spectroscopic Survey (eBOSS) is addressing the issue of the cosmological expansion in unexplored redshift regimes — including the epoch of transition from deceleration to acceleration. To do so, eBOSS will obtain spectra for nearly 700,000 quasars across the redshift range $1.0 < z < 3.5$, over a footprint of 7,500 deg^2. A new sample of $g = 22.0$ "mid-redshift" quasars (630,000 in the range $1 < z < 2.2$), will complement the bright SDSS in luminosity range, and the SDSS-III: BOSS $z > 2.2$ "high-redshift" sample. The eBOSS survey started in September 2014 for a 6 year duration.

SDSS-IV: TDSS: The Time Domain Spectroscopic Survey (TDSS) is another SDSS-IV survey and will select time-variable targets for spectroscopic follow-up. These targets will include quasars and several classes of variable stars, either of which may well reveal previously unidentified phenomena.

I performed 'Key Project' science investigations with SDSS (Ross et al. 2009) and was the Chair of the SDSS-III Quasar Working Group. Critically, however, by returning to Europe, I am no longer part of SDSS-IV and thus currently not leading new analysis in SDSS-IV. To build on my previous investment of effort and expertise, and to restore collaboration and data access, collaboration "buy-in" is required. Part of this grant request is for this SDSS-IV 'buy-in', which allows data rights and collaboration access to the P.I. ***and their associated PDRAs and PhD students****.*

3.3 The Utility of the Mid-Infrared

Mid-infrared (MIR; 3–10μm observed) observations complement both the optical quasar surveys and the X-ray deep fields. MIR colours can efficiently select luminous AGN (Lacy et al. 2004, Stern et al. 2005, Richards et al. 2009b, Donley et al. 2012, Stern et al. 2012, Assef et al. 2013, Richards et al. 2015) but can also select quasars where optical-only selection techniques traditionally fail (Richards et al. 2009b, 2015). Thus, optical+MIR colour selection becomes a very powerful tool, especially at $z > 2.5$.

Meanwhile, although X-rays penetrate low to moderate columns of obscuring dust and gas, 2–10 keV X-ray surveys miss a significant fraction of moderately obscured AGNs ($\sim$25% at $N_{\rm H} = 10^{23}$ cm^{-2}) and *nearly all* Compton-thick AGNs ($N_{\rm H} > 10^{24}$ cm^{-2}; Treister et al. 2004, Ballantyne et al. 2006, Tozzi et al. 2006). Not only does the MIR emission from AGN-heated dust trace the reprocessed radiation absorbed in other wavebands, but it is itself relatively insensitive to intervening obscuration. MIR selection therefore identifies many heavily obscured AGNs nearly half of which are missed in deep X-ray surveys (Alexander et al. 2008; Donley et al. 2008, 2012). The current state-of-the-art mid-infrared survey datasets are provided by the *Spitzer Space Telescope* and the Wide-field Infrared Survey (WISE) Explorer Mission (Wright et al. 2010). At 3-5μm wavelengths, *Spitzer* has imaged $\sim$ few $\times\, 10^2$ deg^2 to μJy depths while WISE has imaged the full sky to mJy depths; thus providing very complementary datasets to each other, and to the wide optical, and deep X-ray, surveys.

3.3.1 Large Mid-Infrared Surveys, (1): SpIES and SHELA

The *Spitzer*-IRAC Equatorial Survey (SpIES) is a postcryogenic (a.k.a Warm) Exploration Class program observing $\sim$110 deg^2 in $\sim$800 hrs to depths of $\approx$5μJy at 3.6μm and $\approx$7μJy at 4.5 μm (5σ, point-source) across the SDSS Stripe 82 field. One of the main science goals of SpIES is to make a new measurement of the (mid-infrared) Quasar Luminosity function. SpIES is complemented on the Stripe 82 field by the completed Spitzer-HETDEX Exploratory Large Area (SHELA) Survey, and indeed the imaging analysis and catalogues that are in the initial stages of preparation now, will ultimately combine both surveys (Timlin, Ross et al. 2015, in prep.).

These data, *which the P.I. has intimate first hand knowledge of and access to*, will also allow us to address the important question of the break luminosity L^* evolution at $z \gtrsim 3$ which is currently only weakly constrained. While Fan et al. (2001a) and Richards et al. (2006b) find that the QLF slope flattens at high-z (consistent with the popular cosmic downsizing scenarios), other work suggests that the slope might still be steep at $z \sim 6$ (Jiang et al. 2009; Willott et al. 2010; McGreer et al. 2013); this discrepancy may simply reflect insufficient knowledge of the break luminosity at high-z. The SpIES data will provide a conclusive answer and will have a significant impact on our understanding on the growth of supermassive BHs and cosmic downsizing.

3.3.2 Large Mid-Infrared Surveys, (2): WISE

The Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) has mapped the full sky in four mid-infrared bands centered on 3.4, 4.6, 12, and 22 μm (W1, W2, W3 and W4, respectively). 95% of the total and 98.6% of the bright $i \leq 19.1$ SDSS quasars are detected in one or more WISE bands (Pâris et al. 2015; Ross et al. 2015b). Detailed studies from Stern et al. (2012) and Assef et al. (2013) determine that completeness and purity of WISE-selected quasar samples and (Assef et al. 2013) define a colour-magnitude cut that finds 130$\pm$4 deg^{-2} AGN candidates with W2$<$ 17.11 and 90% reliability.

Recently, Blain et al. (2014) presented WISE detections of 55% (17/31) of the known quasars at $z > 6$, including ULAS J1120+0641 at $z = 7.01$. *With its all-sky coverage, WISE thus provides a powerful tool for detecting luminous quasars at all redshifts up to and including $z \approx 7$, and will heavily complement optical-selections to sample the bright-end of the QLF.*

4 The MIQSO Projects

4.1 MIQSOs Project 1: A full census of Quasars at $z = 2 - 7$ (3 year PDRA project)

This project will leverage the optical and new mid-infrared datasets to make a complete census of the $z = 2 - 7$ QSO population in order to accurately account for supermassive black hole mass bulid-up.

Science Goal 1: Exploitation of the SDSS+BOSS optical spectroscopy, and the SpIES+WISE MIR data in order to make a mid-infrared quasar luminosity function (QLF) measurement. The QLF is a convolution of the: *(i)* black hole mass function; *(ii)* the efficiency of matter accretion and *(iii)* obscuration fraction, all of which depend (in a poorly understood way) on luminosity and redshift. The current state-of-the-art optical QLF measurements at high-redshift, $z \gtrsim 2$, where model discrimination power is best, are hampered by not knowing the obscuration fraction (e.g. Ross et al. 2013). Assef et al. (2011) and Lacy et al. (2015) present the current best measurement of the mid-infrared QLF, but both of these studies are still hampered at high-z by low number statistics, with only $\sim$100 quasars at $z \geq 3$. Our new deep and wide *Spitzer* survey, will observe $\gtrsim$25,000 unobscured and obscured quasars, with over $\sim$1,200 at $z \geq 3$.

Science Goal 2: A second science aim will be the measurement of the unobscured QLF, down to $g = 22$ and up to $z \approx 5$. eBOSS and TDSS, both include quasars as a major component, but select them very differently, yielding the largest and most complete spectroscopic survey of quasars ever created. The SDSS-IV quasar samples will match the BOSS quasars in luminosity range, but now at redshifts $z < 2$. *Thus, with SDSS-I/II, SDSS-III BOSS and SDSS-IV:eBOSS+TDSS, the luminosity-redshift $(L - z)$ plane for all quasar is fully sampled out to $z \approx 5$ for the first time.*

Science Goal 3: Will be to place these new QLF measurements in context of AGN feedback models, including using the prescriptions found in the latest suite of hydrodynamical cosmological simulations, e.g., Illustris (Vogelsberger et al. 2014) and EAGLE (Schaye et al., 2015; Crain et al. 2015).

Project feasibility, Timeline and role of the P.I. Data from SDSS+BOSS+SpIES+WISE are all in-hand and the necessary catalogues will be produce by the end of 2015/early 2016, well timed for the PDRA to start immediately on the SDSS+SpIES+WISE QLF work. A cosmologically interesting dataset from SDSS-IV eBOSS+TDSS will be in hand by mid-2016. The P.I. is actively involved in producing the catalogues, and will support the PDRA in achieving the science goals.

4.2 MIQSOs Project 2: The Environments of 'Regular' $z > 3$ Quasars (4 year PhD project)

This project will again leverage the optical and new mid-infrared datasets to make the first clustering measurements of faint $z > 3$ quasars. These results will be directly used to constrain AGN feedback models.

Science Goal 1: Will be to make the first ever measurement of the clustering of the faint $z > 3$ MIR-selected quasar population. Hopkins et al. (2007) contrasts the behaviour of quasar clustering strength for 3 flavours of feedback model as a function of survey depth and redshift, demonstrating that they are degenerate in a survey like SDSS due to a lack of dynamic range in quasar luminosity, see Figure 6. However, Hopkins et al. (2007) note that extending the depth of quasar surveys to $i = 23$ (1-2 mags deeper than BOSS) will move further down the QLF, increasing the quasar density enough to break the degeneracy between models at high-z. This measurement will be possible with the new SpIES dataset.

Science Goal 2: Recent measurements at $z \sim 1.5$ (Donoso et al., 2014; DiPompeo et al. 2015) have claimed that the obscured quasar population are at least as strongly clustered as the unobscured (optically selected) quasars. This result has dramatic consequences if confirmed, placing tight constraints on the sequence of evolutionary stages for luminous AGN. Using WISE to perform a similar selection to these studies, BOSS has targeted ∼30,000 mid-IR selected objects, a key goal of which is to perform a clustering measurements with *spectroscopic redshifts* (a key limitation to the Donoso et al. and DiPompeo et al. studies) and to test this intriguing result at high significance and place the quasars in a broader evolutionary context.

Science Goal 3: The eBOSS clustering sample is ≈20× larger than the current best measurement from SDSS in the same redshift range (e.g., Ross et al. 2009). This will lead to the first sub-percent constraint on quasar bias at $z \sim 1.5$, or, match SDSS-level constraints in 20 bins of $dz = 0.1$ and measure bias evolution. This dataset, with its range in luminosity at all redshifts will provide the first meaningful clustering constraints on luminosity-dependent quasar clustering and thus quasar fueling (Lidz et al., 2006). It will also provide a factor of ∼3 improvement in measurement of clustering amplitude in the range $40 < r < 100$ kpc/h, providing the first ∼10% level constraint on fraction of quasars in satellite halos.

Project feasibility, Timeline and role of the PI. Again, the key data are in hand, and will be ready for the PhD student to immediately exploit. The P.I. is the lead on the BOSS+WISE quasar spectroscopic programme. The P.I. has experience in writing clustering code and the relevant data analysis, but the student would be encouraged to further develop the analysis techniques. The P.I would naturally play an active supervisory role in all these research activities.

4.3 MIQSOs Project 3: Early Science with *The James Webb Space Telescope* (P.I. Led Project)

The *James Webb Space Telescope* (*JWST*) is a 6.5-meter infrared telescope that will initiate and enable completely transformative science. Due to its collecting area and wavelength coverage, in many ways, *JWST* is not "*Hubble's* successor", but more like a "Super-*Spitzer*" and a "Mega-WISE" combined in one. This project is designed to ramp up to the launch of the James Webb Space

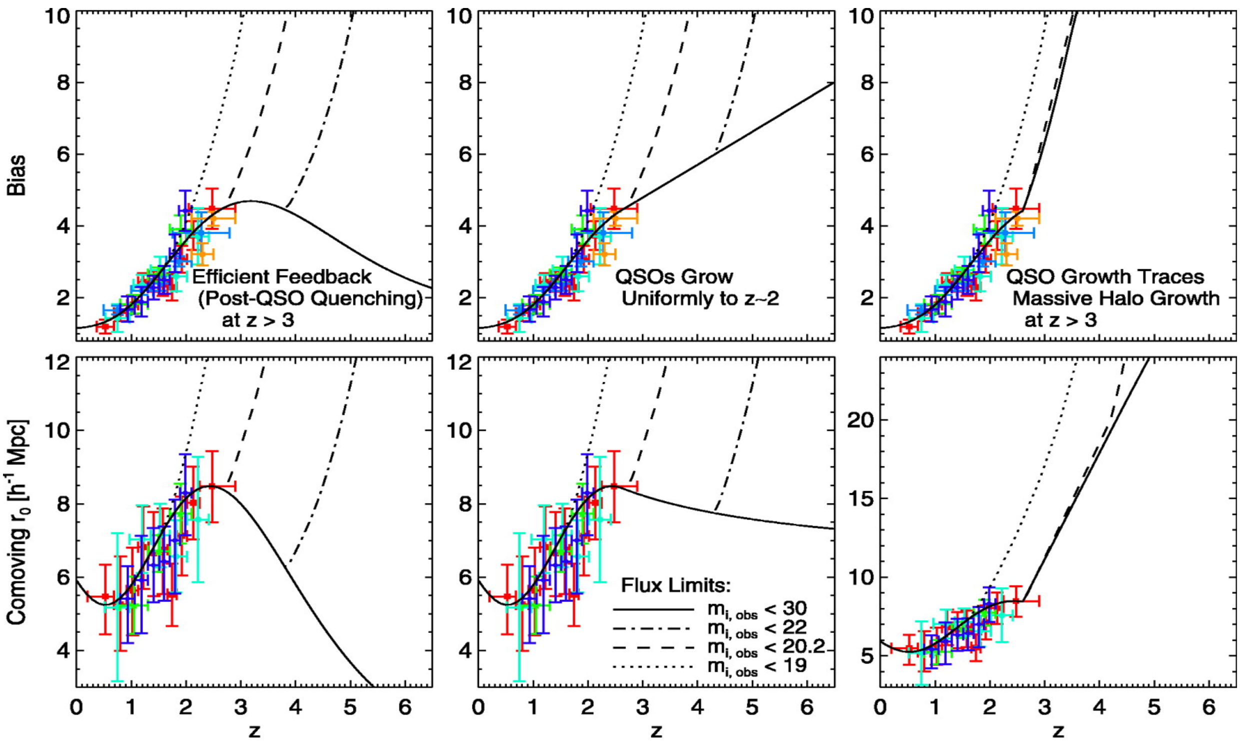


Figure 6: Different feedback models from Hopkins et al. (2007) make different predictions for quasar bias (as a measure of clustering strength). The models predict similar clustering at $z < 2$, as observed (points; e.g. Croom et al., 2005; Myers et al. 2006, 2007a,b; Ross et al. 2009) but the models diverge at high-z. We compare the current SDSS (dotted) and SpIES (dash-dot) flux limits and an infinitely deep survey (solid). Only a deep spectroscopic survey, or a survey with photometric redshifts comparable to those of SpIES, across a large range in luminosity, can distinguish competing feedback models. The models are: *Left:* strong feedback, where every high-z quasar is in "blowout mode", about to shut down for a Hubble time; *Center:* "standard feedback", in which the BH and halo are co-eval, and *Right:* a model in which high-z quasars do not regulate their hosts at all, continuing to grow their BHs rapidly until $z = 2$.

Telescope and plan for the Early Release Science (ERS) program, a suite of new observations that will become immediately public very early in *JWST* observing.

Science Goal 1: The discovery of the extremely red quasars (Ross et al. 2014) seems to provide a key observational clue to the "major merger" evolutionary theory for quasar activity (Hopkins et al. 2006). The P.I. is a lead Co-I in a small team of 9 members that is acquiring time on 8-10m class telescopes in order to understand these potentially really important objects. So far we have data from VLT XShooter, and have recently been granted time in 2015A and 2015B on Keck One (LRIS spectropolarimetry), Gemini North (GNIRS spectroscopy) and the LBT (LUCI+MODS Opt/NIR spectroscopy). The P.I. will lead these joint data analyses (and if necessary further follow-up proposals) and the subsequent interpretation, modeling and paper production.

Science Goal 2: There will be an Early Release Science (ERS) program, that will take maximal advantage of *JWST's* new and uniquely powerful capabilities immediately upon commencing science operations. One natural ERS case for *JWST* is the investigation of obscured and very red quasars, using the MIRI spectrograph, and by utilizing all my experience with mid-infrared datasets, surveys and object discovery, I am positioning myself to carry out these investigations. *A call to the community to define ERS science has been issued and I will become a lead European Investigator and responsible for this revolutionary mission.* The *JWST* is scheduled for launch in late 2018, which due to the project's scheduled reserve is now very feasible. Regardless, the ERS Science case will be written over the course of the ERC 2015 Starter Grant, and even a year's delay in launch (i.e. an actual 2 year delay taking into account the current reserve) sees the non-proprietary ERS data delivered before the end of the grant.

Project feasibility, Timeline and role of the PI. All the necessary data for immediate red quasar follow-up are in hand, or will be by the end of 2015. The JWST ERS Science call is being released in 2015 (see the "From Launch to Science Operations" slides at http://www.stsci.edu/jwst/doc-archive/presentations) and with the P.I.'s experience in MIR surveys and target selection, I have already been in contact with the STScI in order to play a lead role in putting the ERS case together.

In summary, I request funding for the full 5-yr period for the ERC Starter Grant. This includes support for the P.I. (at 100%) for 5 years, a PDRA (at 100% for 3 years) and a PhD student (100% for 4 years). I also request 'buy-in' to the SDSS-IV project and allows data and collaboration access for the P.I., the PDRA and PhD student. Additional project funds are requested for computing resources and travel for conferences, observing runs and collaboration meetings.

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5 Resources (including project costs)

Cost Category	Total in Euro		
Direct Costs	**Personnel**	PI	421,195
		Senior Staff	
		Postdocs	185,682
		Students	208,050
		Other	
	i. Total Direct Costs for Personnel (in Euro)		814,926
	Travel		67,500
	Equipment		
	Other goods and services	Consumables	67,500
		Publications (including Open Access fees), etc.	0
		Other, incl. SDSS-IV Project buy-in, Audit, Recruitment, Publication.	99,900
	ii. Total Other Direct Costs (in Euro)		234,900
A – Total Direct Costs (i + ii) (in Euro)			1,049,826
B – Indirect Costs (overheads) 25% of Direct Costs (in Euro)			262,457
C1 – Subcontracting Costs (no overheads) (in Euro)			0
C2 – Other Direct Costs with no overheads (in Euro)			0
Total Estimated Eligible Costs (A + B + C) (in Euro)			1,312,283
Total Requested EU Contribution (in Euro)[6]			1,312,283

For the above cost table, please indicate the duration of the project in months:	60
For the above cost table, please indicate the % of working time the PI dedicates to the project over the period of the grant:	**100%**

The P.I. will spend 100% of their time on the project, which will include achieving the science objectives, managing and supervising personal, as well as the associated logistical overhead time commitments.

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COMMITMENT OF THE HOST INSTITUTION

Commitment of the host institution for ERC Calls 2015

The University of Edinburgh, which is the *applicant legal entity*, confirms its intention to sign a supplementary agreement with *Dr Nicholas Ross* in which the obligations listed below will be addressed should the proposal entitled *MIQSOS: Connecting quasars with galaxy formation via Mid-infrared observations and Next Generation Telescopes* be retained.

Performance obligations of the applicant legal entity that will become the beneficiary of the grant agreement, should the proposal be retained and the preparation of the grant agreement be successfully concluded:

The *applicant legal entity* commits itself to engage the *principal investigator* for the duration of the grant to:

a) ensure that the work will be performed under the scientific guidance of the *principal investigator* who is expected to devote:
- *in the case of a Starting Grant at least 50% of her/his total working time* to the ERC-funded project and spend at least 50% of her/his total working time in an EU Member State or associated country;
- in the case of a *Consolidator Grant at least 40% of her/his total working time* to the ERC-funded project and spend at least 50% of her/his total working time in an EU Member State or associated country;
- *in the case of an Advanced Grant at least 30% of her/his total working time* to the ERC funded project and spend at least 50% of her/his total working time in an EU Member State or associated country.

b) carry out the work to be performed, as it will be identified in Annex 1 of the ERC Grant Agreement, taking into consideration the specific role of the principal investigator;

c) establish a supplementary agreement with the principal investigator which specifies that the applicant legal entity shall:

i) support the principal investigator in the management of the team and provide reasonable administrative assistance to the principal investigator, in particular as regards:

a. the timeliness and clarity of financial information,
b. the general management and reporting of finances,
c. the advice on internal applicant legal entity management practices,
d. the organisation of project meetings as well as the general logistics of the project.

ii) provide research support to the principal investigator and his/her team members throughout the duration of the project in accordance with Annex 1 ERC Grant Agreement, in particular as regards infrastructure, equipment, products, access rights and other services as necessary for the conduct of the research;

iii) ensure that the principal investigator and his/her team members enjoy, on a royalty-free basis, access rights to the background and the results needed for their activities under the project as specified in Annex 1 ERC Grant Agreement;

iv) ensure that the principal investigator enjoys adequate contractual conditions, in particular as regards:

a. the provisions for annual, sickness and parental leave,
b. occupational health and safety standards,
c. the general social security scheme, such as pension rights.

v) guarantee the necessary scientific independence of the principal investigator, in particular as regards:

a. the selection and supervision of other team members, hosted and engaged by the applicant legal entity or other legal entities, in line with profiles needed to conduct the research, including the appropriate advertisement, and in accordance with the beneficiary's usual management practices;
b. the use of the budget to achieve the scientific objectives;
c. the preparation of scientific reports to the ERC Executive Agency;
d. the authority to publish as senior author and invite as co-authors only those who have contributed substantially to the reported work.

vi) inform the principal investigator of any circumstances affecting the implementation of the project or leading potentially to a suspension or termination of the ERC Grant Agreement;

vii) subject to the observance of applicable national law and to the agreement of the ERC Executive Agency, the transfer of the grant agreement as well as any prefinancing of the grant not covered by an accepted cost claim to a new legal entity, should the principal investigator request to transfer the entire project or part of it to this new legal entity. The applicant legal entity shall submit a substantiated request for amendment or notify the ERC Executive Agency in case of its objection to the transfer.

For the institution: The University of Edinburgh
Name: Angela Noble
Function: Senior European Funding Advisor
Email: Angela.Noble@ed.ac.uk
Signature of legal representative: A. Noble.

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UNIVERSITY OF DURHAM

NICHOLAS PATRICK ROSS OF TREVELYAN COLLEGE, HAS BEEN AWARDED

DOCTOR OF PHILOSOPHY

IN THE FACULTY OF SCIENCE

11 JANUARY 2008

Bill Bryson

CHANCELLOR

Lee Sanders

REGISTRAR AND SECRETARY

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