VICTORIA
UNIVERSITY OF WELLINGTON

Confirmation of Master's Thesis Research Proposal
Reference: Master's Thesis Policy section 4.3

Sections A and B must be completed by the candidate and the supervisor and attached to the research proposal. The research proposal should not normally exceed 5 pages or 2,500 words and must be submitted to the School Research Committee within one month of a candidate's enrolment in a Master's thesis. For students who are enrolled half-time, this form should be completed within two months. Please note that some Schools may require candidates to submit a research proposal before the end of part one of a Master's programme.

SECTION A

Candidate's last name: MOSS

Student ID number: 300476658

First name: JEREMY

Scholarship/external funding: □ Yes ☑ No

Degree: MSc

Subject: Astronomy

Enrolment status: ☑ Full-time   □ Half-time

Thesis working title: DEVELOPING A PHOTOMETRIC ESTIMATE OF QUASAR REDSHIFTS

Supervisor's name: DR STEPHEN CURRAN

Second or co-supervisor (if applicable):

Date of enrolment for the thesis: 2/7/2018

SECTION B – to be completed by the candidate

1. RESEARCH PROPOSAL
☑   My research proposal is attached.

2. RESEARCH INFORMATION
It is important that you are aware of the University's expectations and understand your responsibilities as a researcher. You need to be familiar with the relevant information noted below and should have discussed with your supervisor how this information applies to you before you submit your research proposal for approval.

I have read and discussed the information at the links below with my supervisor:

Master's Thesis Policy information
☑   Time limits for thesis submission (section 4.9 c)
☑   Due dates for progress reports (section 4.8 c)
☑   Attendance at the University (section 4.5)
☑   Word limits for theses (section 4.9 a & b)
Other relevant information
☑   Academic integrity
☑   Proofreading and Editorial Advice Policy and Guidelines
☑   Recognition of Authorship Policy
☑   Withholding of Theses Procedure

3. ETHICS APPROVAL
3.1 Does your research require ethics approval?
□ Yes   ☑ No (go to question 4)

3.2 Have you applied for ethics approval?

☐ Yes ☐ No

If yes, please enter

Date of application:	Date approved:	Application number:

If no, please comment:

4. INTELLECTUAL PROPERTY

If your thesis is likely to contain an invention, discovery or creation which may be protected by way of trademark, patent, copyright etc you will need to enter an agreement to protect your intellectual property rights. Refer to the Intellectual Property Policy. Similarly, if you need to obtain access to specific data or other intellectual property, you will need to obtain consent to do so.

4.1 Are you are likely to create intellectual property in association with your thesis that is notifiable in accordance with the University policy?

☐ Yes ☒ No (go to question 4.2)

If yes, please enter date agreement signed:

If an agreement has not been signed, please comment:

4.2 Do you require access to specific data or other intellectual property in association with your thesis?

☐ Yes ☒ No (go to question 5)

If yes, please enter date agreement giving consent signed:

If consent has not been obtained, please comment:

5. EXTERNAL PARTY INVOLVEMENT

Is an external party involved in your thesis work? (See Master's Thesis Policy section 4.6)

☐ Yes ☒ No (go to question 6)

If yes, please enter date memorandum signed:

If a memorandum has not been signed, please comment:

6. ATTENDANCE AT THE UNIVERSITY

If you are going to be away from the University to undertake your research, has your off-campus work been approved by your School? (See Master's Thesis Policy section 4.5)

☑ Yes   ☐ No (go to question 7)   ☐ N/A No off-campus work is anticipated (go to question 7)

If yes, please enter date approval signed:

AND

☐ Attach the approval document to your research proposal.

If an approval has not been signed, please comment:

7. ADDITIONAL RESOURCES (see Master's Thesis Policy section 4.4)

If your thesis requires resources in addition to those covered by the Minimum Resources Agreement, details must be provided in the Research Proposal and a resource memorandum negotiated with your School.

Does your thesis require additional resources?

☐ Yes   ☑ No (go to number 8)

If yes, please enter date resource memorandum signed with the School:

If a resource memorandum has not been signed, please comment:

8. JOINT STATEMENT

We confirm that we have read and discussed the information listed in section B.2 and where necessary approvals have not yet been obtained a plan is in place to obtain them.

Signed by
Candidate
Name: JEREMY MOSS   Signature: Date: 24/7/2018

Supervisor
Name: Signature: Date:

SECTION C

To be completed by the School Research Committee (SRC) in consultation with the supervisor/s

	N/a	Satisfactory	Reservations (with comment)
Aim of thesis project			
Method of study			
Scope appropriate for the degree			
Ethical considerations			
Resource requirements			
Supervisory arrangements			
External party involvement			
Other			

RECOMMENDATION - The SRC recommends that the research proposal is:

☐   Approved

☐   Not approved

☐   Approved subject to meeting the following conditions:

Enter date for conditions to be met:

Signed by Convener of SRC

Name: Signature: Date:

SECTION D - APPROVAL

To be completed by Head of School (or nominee)

The Research Proposal is:

☐   Approved

☐   Not approved

☐   Approved subject to meeting the conditions specified by SRC in section C above

☐   Approved subject to other conditions as specified below:

Enter date for other conditions to be met:

Signed by HoS (or nominee)

Name: Signature: Date:

SECTION E

To be actioned by the School Office

☐   Copy to student   Date:

☐   Copy to supervisor   Date:

☐   Original to Faculty Office   Date:

☐   *If there are conditions still to be met, send a COPY of this form*
to the Faculty Office   Date:

☐   AND send the original once the conditions have been fulfilled   Date:

☐   If the scholarship box in Section A is ticked, copy to Scholarships.   Date:

Developing a photometric estimate of quasar redshifts

An independent measure to the distances to the most powerful objects in the Universe

Motivation

Hydrogen is the most common form of baryonic (normal) matter, and is the fundamental building block of all stars, which subsequently provide the heavier elements found in planets and life. As such, it plays a critical role in our understanding of the history and evolution of our Universe. Hydrogen emits radio waves with a characteristic wavelength of 21 cm. Unlike visible light, radio waves are not absorbed or scattered by interstellar dust, water vapour and daylight, being observable from Earth 24 hours a day, and across the entire Universe.

To search for an object in any wavelength, we need to know not only its position in the sky, but also a redshift to which to tune the receiver. This redshift is related closely to the distance to the object (see Figure 1), and usually, this comes from spectroscopic observation of its optical light. Since intervening clouds of dust and gas absorb visible light, this introduces a selection bias against dimmer sources, those which contain the cold, neutral gas. Optically dim objects which are rich in hydrogen remain undetected, even with the world's largest optical instruments; thus, being able to determine the redshift without requiring an optical spectrum would be extremely useful.
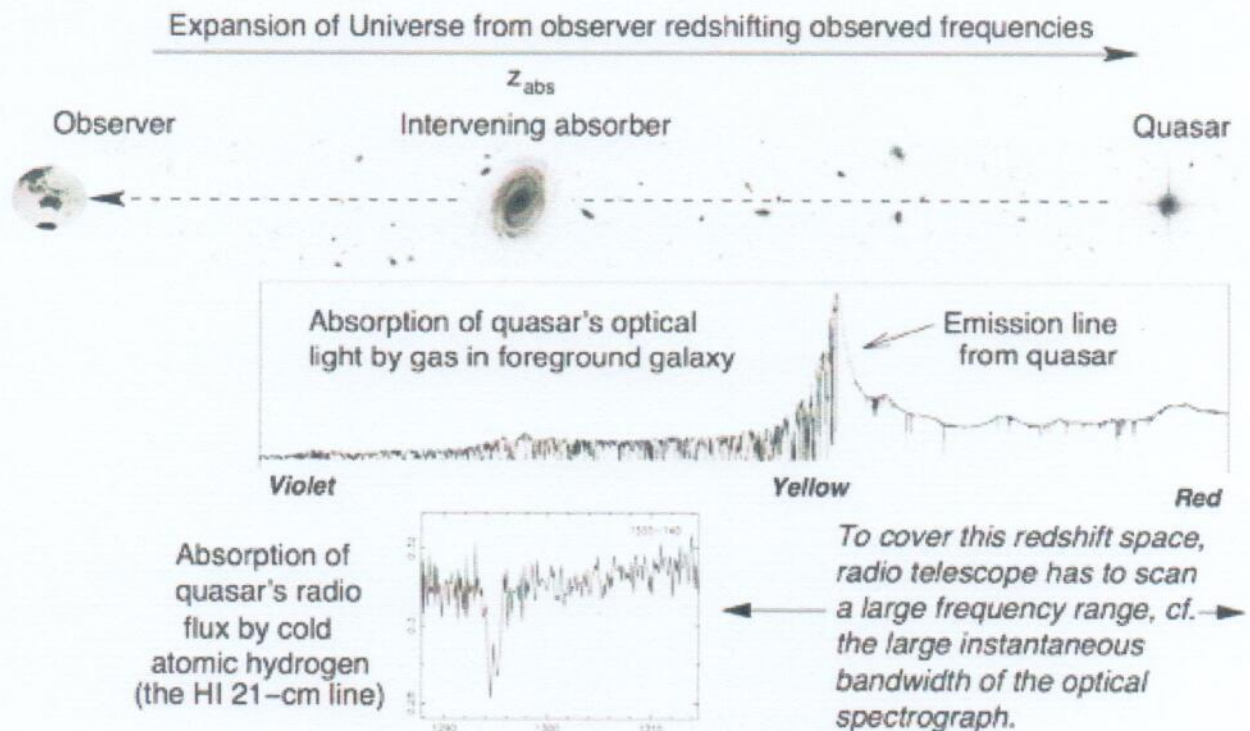

Figure 1: The radiation from a quasar is absorbed at a (rest-frame) wavelength of 21 centimetres by the cool hydrogen gas in an intervening galaxy or cold gas cloud.

Most large galaxies contain a supermassive black hole (SMBH), nestled at the core of the galaxy. This black hole can mass in the range of millions, to billions of solar masses. For example, our Milky Way Galaxy's black hole has a mass of approximately 4.2 million solar masses [1]. With

such a relatively small mass, our galactic black hole is inactive. In galaxies with an extremely large SMBH, the surrounding accretion disk can give off huge amounts of energy in ultraviolet radiation, in some cases on the order of 10^{39} watts [2]. This is called an *active galactic nucleus* (AGN), or *quasar*. This phenomenal energy output allows quasars to be visible across the entire Universe.

In the case of some of the most active of AGNs, such as S5 0014+81, the central black hole is accreting material at a rate of several Earth-masses per second (Prof. Rob Jeffries, University of Keele, Staffordshire, UK [personal communication, July 4, 2018]). Figure 2 shows another example; 3C273, the first quasar identified.

Figure 2: One of the brightest known quasars, and, in 1963, the first ever discovered, 3C273, is accreting roughly 0.2 Earth masses per second. Note the presence of a jet of charged particles (10 o'clock position) propelled outward by the energy generated near the black hole. This jet measures some 200,000 light-years in length.

Project description

A correlation has been found between the near-infrared K-magnitude ($\lambda = 2.2\mu$m) and the redshift of the source [4]. See Figure 3. The WISE spacecraft (*Wide-field Infrared Survey Explorer*) makes observations in four mid-infrared wavelength range bands: 3.4, 4.6, 12 and 22 μm. The correlation is also apparent at the *W1* band ($\lambda = 3.4\mu$m), since these two wavelengths are reasonably close. This means that the redshifts of galaxies with relatively quiescent central black holes can be reasonably predicted from their apparent near-infrared flux. Some correlation is to expected, since objects which are farther away are fainter, but the fact that it is so linear is remarkable. We would expect each galaxy to have its own individual properties, but the tight linear correlation suggests that these properties have little influence on the magnitude.

However, when the same method is applied to quasars, we find that the K-z fit drastically underestimates the redshift of the source (Figure 4). This is probably because, in the case of a quasar, the light spectrum is dominated by the AGN, in addition to the galactic stellar population. This results in a higher emission in the near infra-red wavelengths than the galactic model predicts.
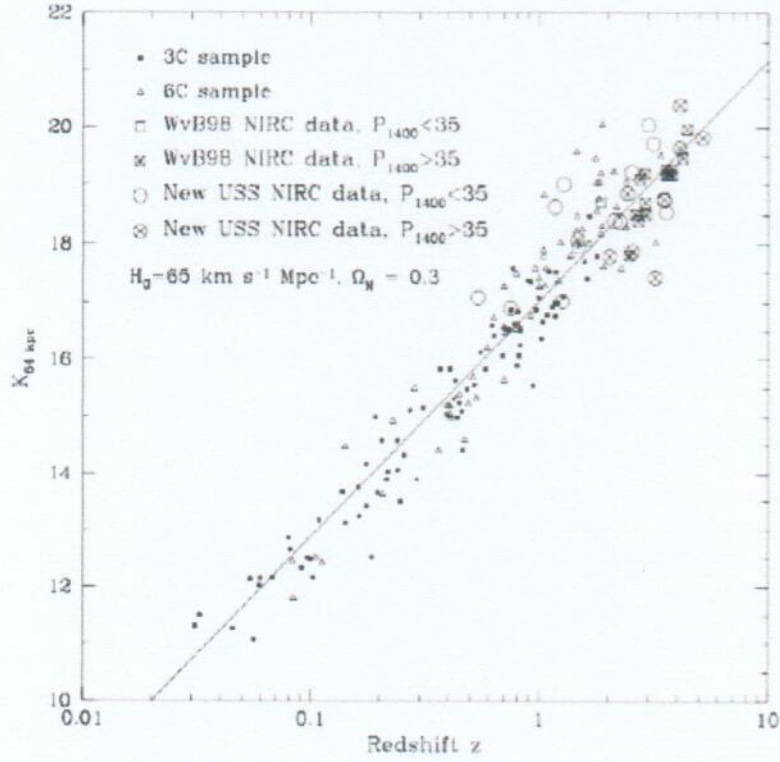
Figure 3: Plot of K-magnitude ($\lambda = 2.2\mu m$) against redshift for galaxies. Such a tight fit is remarkable, since each galaxy has its own individual properties. K-magnitude is $K = 4.43 \log_{10} z + 17$
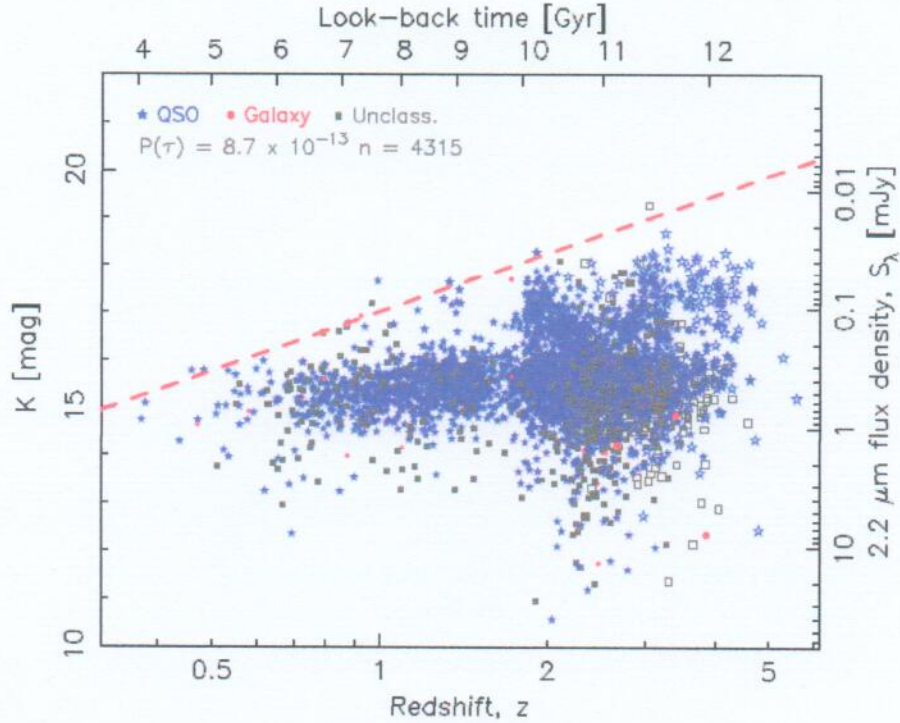

Figure 4: Plot of K-z fit for a large sample of quasars. The broken line shows the above fit for galaxies, demonstrating that the K-magnitude underestimates redshift in the case of quasars.

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This work will benefit some of the world's largest multi-wavelength surveys, including the *Square Kilometre Array* (SKA) and its pathfinder *Australian SKA Pathfinder* (ASKAP). For example, the *Evolutionary Map of the Universe* (EMU) [5], a survey on the ASKAP, will detect about 70 million radio sources, and most of these will be galaxies containing massive black holes. Due to the nature of the survey, the spectra taken by EMU will be of insufficient resolution to determine the redshifts. If these can be estimated from the photometry, the value of the survey in determining how gas, stars and energetic phenomena such as black holes and quasars are distributed throughout the Universe will increase dramatically. Even an approximate or statistical estimate of the redshift would be valuable.

Aim

These observations show strong correlations between the K-magnitude and z for quasars [3] , giving a straight-line fit in log-space, but the regression coefficient is too low (*i.e.* the points are too scattered) to provide a useful estimate of the redshift of the object.

This project aims to find a magnitude, or a combination of magnitudes, which can improve the prediction of the straight-line fit to quasar sources by maximising the regression coefficient to account for the contribution in near infra-red wavelengths of the AGN. In this way, we aim to find a relation close enough to make redshift predictions. If successful, this work will also give great insight into the contribution of the black hole to the photometry of these objects, leading to an improved understanding of the underlying physical processes in the most powerful objects in the Universe.

Bibliography

[1] J. Bland-Hawthorn and O. Gerhard. The Galaxy in Context: Structural, Kinematic, and Integrated Properties. *ARA&A*, 54:529–596, September 2016.

[2] B. C. J. Borguet, N. Arav, D. Edmonds, C. Chamberlain, and C. Benn. Major Contributor to AGN Feedback: VLT X-shooter Observations of S IV BALQSO Outflows. *ARA&A*, 762:49, January 2013.

[3] S. J. Curran and S. W. Duchesne. The mid-infrared properties and gas content of active galaxies over large lookback times. *MNRAS*, 476:3580–3590, May 2018.

[4] M. Glowacki, J. R. Allison, E. M. Sadler, V. A. Moss, and T. H. Jarrett. WISE data as a photometric redshift indicator for radio AGN. *ArXiv e-prints*, September 2017.

[5] R. P. Norris, A. M. Hopkins, J. Afonso, S. Brown, J. J. Condon, L. Dunne, I. Feain, R. Hollow, M. Jarvis, M. Johnston-Hollitt, E. Lenc, E. Middelberg, P. Padovani, I. Prandoni, L. Rudnick, N. Seymour, G. Umana, H. Andernach, D. M. Alexander, P. N. Appleton, D. Bacon, J. Banfield, W. Becker, M. J. I. Brown, P. Ciliegi, C. Jackson, S. Eales, A. C. Edge, B. M. Gaensler, G. Giovannini, C. A. Hales, P. Hancock, M. T. Huynh, E. Ibar, R. J. Ivison, R. Kennicutt, A. E. Kimball, A. M. Koekemoer, B. S. Koribalski, Á. R. López-Sánchez, M. Y. Mao, T. Murphy, H. Messias, K. A. Pimbblet, A. Raccanelli, K. E. Randall, T. H. Reiprich, I. G. Roseboom, H. Röttgering, D. J. Saikia, R. G. Sharp, O. B. Slee, I. Smail, M. A. Thompson, J. S. Urquhart, J. V. Wall, and G.-B. Zhao. EMU: Evolutionary Map of the Universe. *PASA*, 28:215–248, August 2011.