

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.

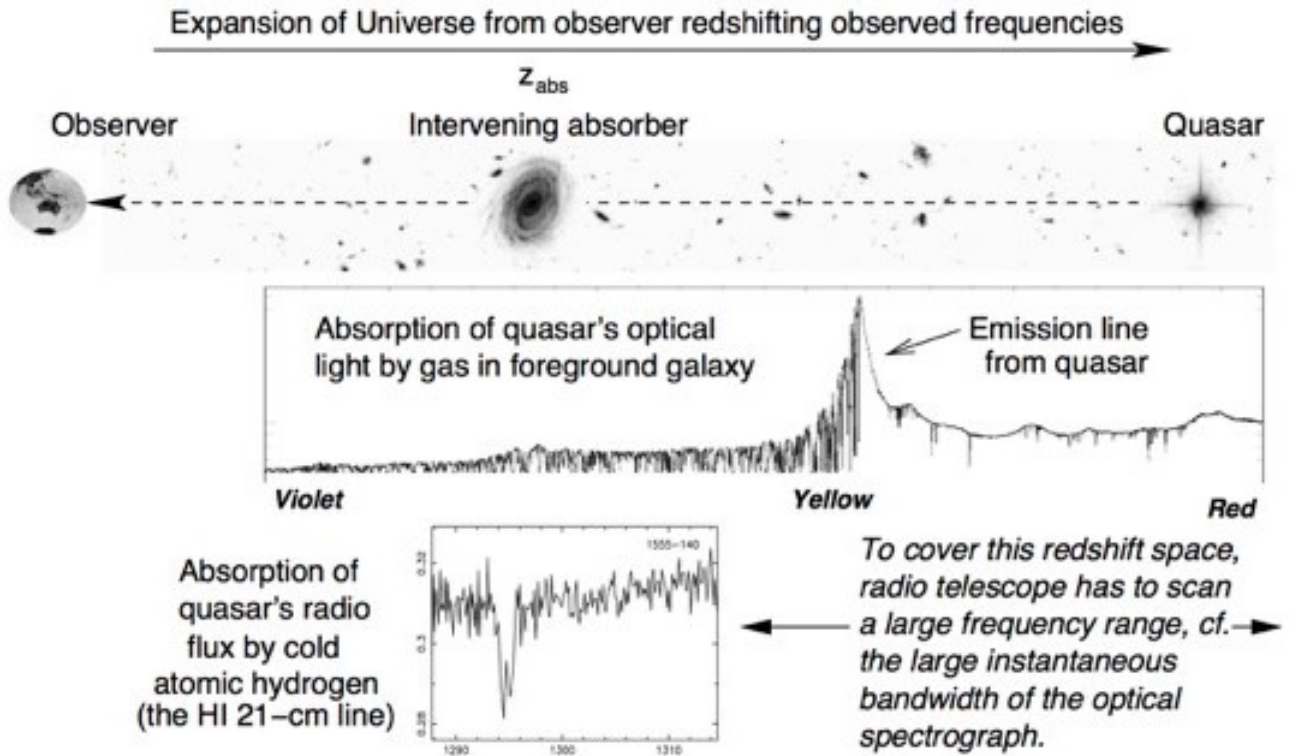


Figure 1: The radiation from a quasar is absorbed at a (rest-frame) wavelength of 21 centimetres by the cool hydrogen gas in an intervening galaxy or cold gas cloud.

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.

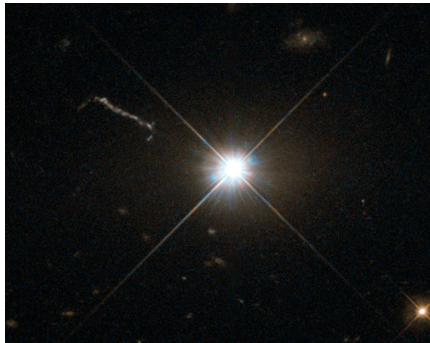


Figure 2: One of the brightest known quasars, and, in 1963, the first ever discovered, 3C273, is accreting roughly 0.2 Earth masses per second. Note the presence of a jet of charged particles (10 o'clock position) propelled outward by the energy generated near the black hole. This jet measures some 200,000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

Project description

A correlation has been found between the near-infrared K -magnitude ($\lambda = 2.2\mu\text{m}$) 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 $22\mu\text{m}$. The correlation is also apparent at the $W1$ band ($\lambda = 3.4\mu\text{m}$), 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.

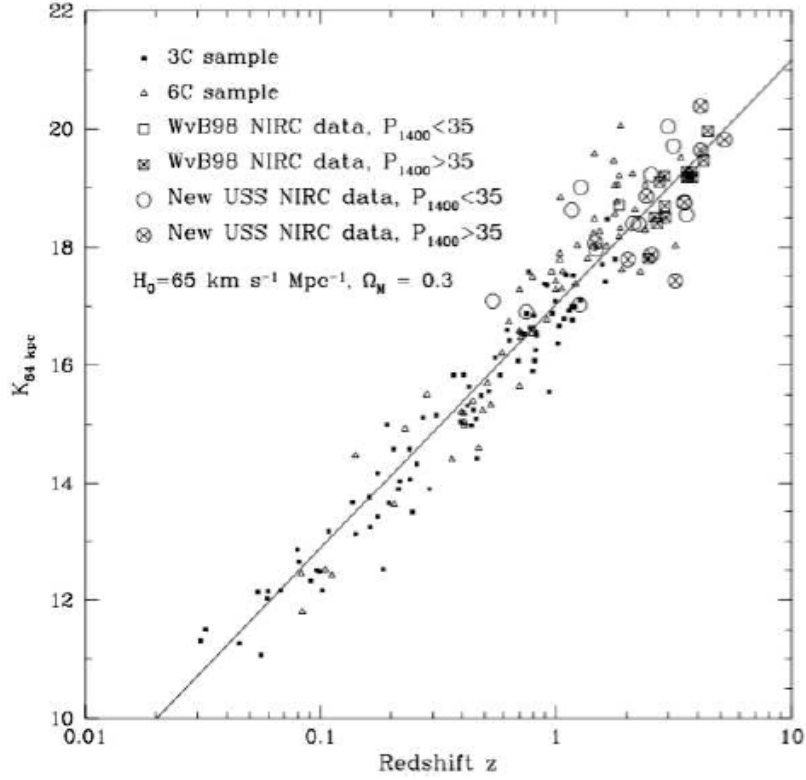


Figure 3: Plot of K -magnitude ($\lambda = 2.2\mu\text{m}$) against redshift for galaxies. Such a tight fit is remarkable, since each galaxy has its own individual properties. K -magnitude is $K = 4.43 \log_{10} z + 17$

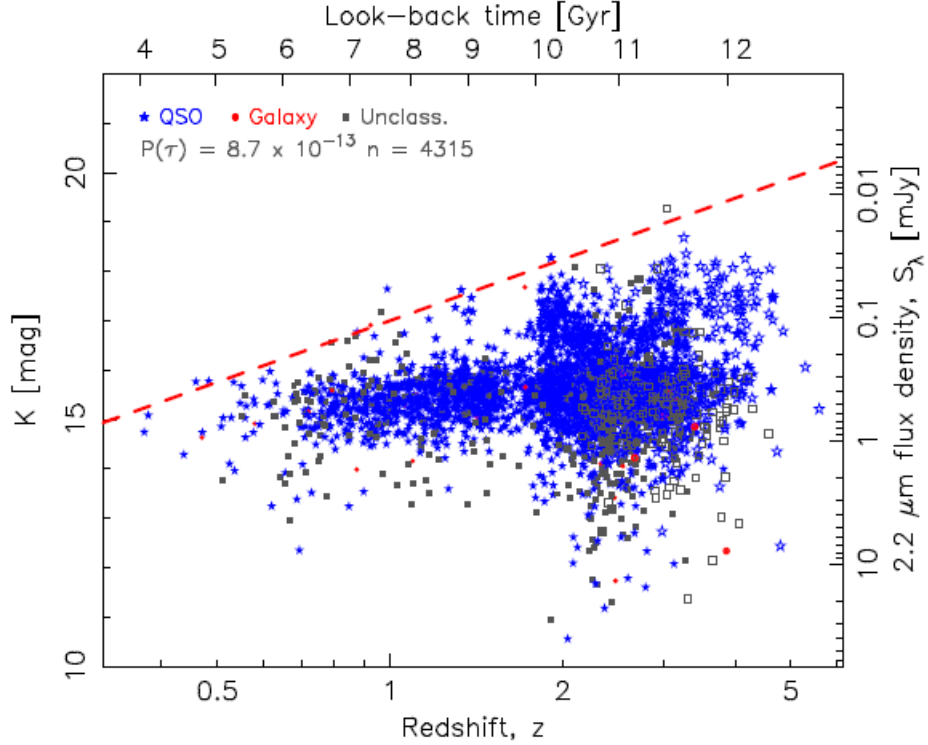


Figure 4: Plot of K - z fit for a large sample of quasars. The broken line shows the above fit for galaxies, demonstrating that the K -magnitude underestimates redshift in the case of quasars.

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