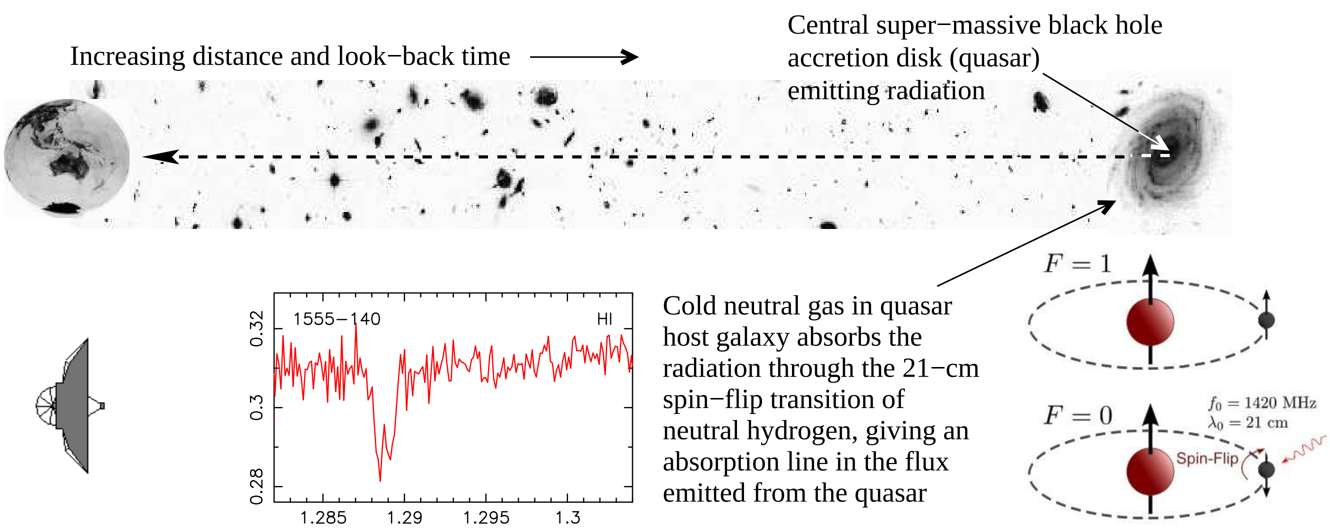
Developing a Photometric Redshift for Quasars

Background and Motivation

Hydrogen gas supplies the Universe with warmth and light and is its most common form of baryonic (normal) matter. While stars themselves are hot, they can only form from the coldest gas (10 degrees above absolute zero), in which a giant (light-year, ~ 10 trillion km) cloud of hydrogen can collapse under its own gravity. Once nuclear fusion ignites the proto-star, the stars in turn process the hydrogen into the heavier elements required for the formation of terrestrial (rocky) planets and life. Thus, the study of cold hydrogen in the distant (and therefore ancient) reaches of space is crucial to our understanding of how the present-day Universe came to be.

Hydrogen gas is a major constituent of galaxies, the cool component of which is detected by radio telescopes via the spectroscopy of atomic hydrogen (H I), when the electron in the atom flips its spin direction upon emitting or absorbing a photon with a wavelength of 21 centimetres. Unlike visible light, radio waves travel freely through interstellar dust, water vapour and daylight, being observable from the ground 24 hours a day and across the entire Universe.



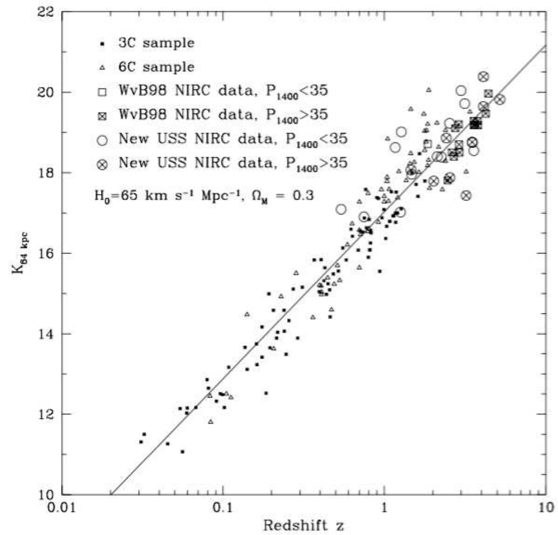
The radiation from a quasar is absorbed at a (rest-frame) wavelength of 21 centimetres by the cool hydrogen gas in the galaxy in which it is located.

To search for this hydrogen, in addition to the coordinates of a radio source on the sky (right ascension and declination), we require a redshift to which to tune the receiver, which is usually obtained from an optical spectrum. However, this introduces a bias towards the most optically bright objects, which are not conducive to the presence of cold, neutral (star-forming) gas. Radio observations reveal much more of the Universe than visible light, penetrating the dusty obscured regions of space (e.g. the dark patches in the Milky Way).

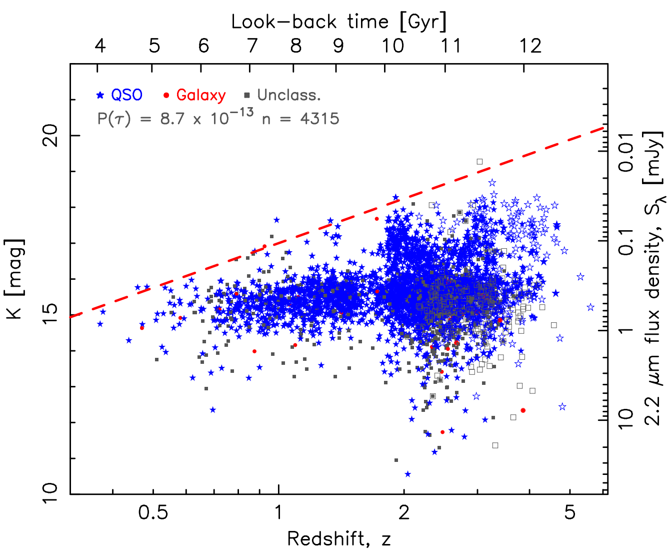
An important contribution to current extragalactic and high redshift astronomy, would be the determination of the redshift of the source based upon the its photometric properties alone (its brightness at various wavelengths). This method has had some success, but usually involves comparing a template for a known type of object with the full spectral energy distribution (SED) of the source (see here). This in not practical for a large number of sources with limited data and so not requiring template fitting of a full SED would prove invaluable in yielding a redshift with which to tune the radio telescope's receiver in the search for 21-cm absorption. Even an approximate or statistical redshift would prove invaluable to the next generation of continuum surveys with the *Square Kilometre Array* (SKA), which will be with world's largest scientific instrument, and its pathfinders. For example, the *Evolutionary Map of the Universe* (EMU), which will take a census of 70 million radio sources in the sky. Being a continuum survey, the spectra will be of insufficient resolution to determine the redshifts, but if these can be estimated from the photometry, the value of the survey in determining how the Universe is populated will increase dramatically.

The Nitty Gritty

A correlation has been found between the near-infrared K-magnitude ($\lambda = 2.2\ \mu$m) and the redshift of the source in the case of *galaxies* (figure to right, De Breuck et al. 2002). Since the higher the magnitude the fainter the source, the magnitude may be expected to increase with redshift (distance), although, given that each galaxy has its own individual properties such a tight fit is remarkable. This applies only to galaxies and including quasars, a correlation has also been found between the W1 magnitude of the *Wide-Field Infrared Survey Explorer* (WISE), which is not surprising since this is close to the K-magnitude with $\lambda = 3.4\ \mu$m (Glowacki et al., 2018). However, although the correlation is strong (Curran & Duchesne, 2018), the spread is too wide to provide a useful predictor of redshift.



It is the aim of this project to obtain a tighter photometric predictor of redshift for *all* radio sources.



The plot to the left shows the $K - z$ distribution for a large sample of *quasi-stellar objects* (QSOs), where the broken line shows the above fit to the galaxies ($K = 4.43 \log_{10} z + 17$), demonstrating that the K-magnitude underestimates the redshift in the case of quasars/QSOs. In other words, at a given redshift, a quasar is brighter in near-infrared (NIR) emission than a galaxy (note the flux scale to the right of the plot). In quasars the light is dominated by an *active galactic nucleus* (AGN) rather than the starlight in the host galaxy, and so there is an additional contribution to the NIR emission, over and above that from stars seen in the case of the galaxies.

Since the $K - z$ distribution for quasars is scattered to the left of the fit, there must be a range of AGN contributions and it is hoped that by correcting the K-magnitude with some other magnitude (or combination of magnitudes) which is (are) sensitive to the AGN contribution, this can be removed, thus yielding a tight relationship with the redshift.

Like Glowacki et al. (2018), very strong correlations are found between various WISE magnitudes and the redshift (e.g. W1-z), but on their own none of these are tight enough to predict the redshift – the plots above show $\log_{10} z$. Therefore, rather than maximising the strength of the correlation, the aim is to find the combination of magnitudes which maximises the regression coefficient (how well the data can be fit by a straight line). E.g. the W1-$\log_{10} z$ correlation has a probability of just $P(\tau) = 1.30 \times 10^{-118}$ of occuring by chance, although the regression coefficient is only $r = 50\%$

References

Curran S. J., Duchesne S. W., 2018, Mon. Not. R. astr. Soc., 476, 3580

De Breuck C., van Breugel W., Stanford S. A., Röttgering H., Miley G., Stern D., 2002, Astron. J., 123, 637

Glowacki M., Allison J. R., Sadler E. M., Moss V. A., Jarrett T. H., 2018, Mon. Not. R. astr. Soc., submitted (arXiv:1709.08634)