Obtaining Spectroscopic Redshifts in the WEAVE-LOFAR Survey

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Abstract

We present a method to obtain spectroscopic redshifts for emission line dominated sources by analysing the spectra in the wavelength range 3676Å to 9594Å. The simulated dataset used in this project comes from the third operational rehearsal of WEAVE-LOFAR. The WEAVE-LOFAR survey uses a Multi-Object Spectrograph to target low-frequency radio sources because of the widespread bright emission lines of star-forming galaxies and Active Galactic Nuclei (AGN) that are principal components of the radio source population. This allows us to detect more galaxies at higher redshifts than a similar telescope could for an optical/near-infrared continuum magnitude-selected sample. The method presented here uses computer generated emission-line templates of galaxies which were cross- correlated against the spectra. The cross-correlation functions allow us to estimate the redshifts precisely. This method is particularly useful at high redshifts where traditional methods of redshift estimation like photometry and model fitting may not produce optimal results.

Methodology

WEAVE (WHT Enhanced Area Velocity Explorer) is a new multi-object survey spectrograph for the 4.2m William Herschel Telescope (WHT) at La Palma in the Canary Islands. WEAVE's fibre-fed spectrograph obtains optical spectra of up to ~1000 targets over a two-degree field of view in a single exposure and comprises two arms: one optimised for the blue (3676Å - 6088Å) and one for the red (5772Å - 9594Å). The WEAVE-LOFAR (Smith et al. 2016) survey targets ~10^6 low-frequency radio sources, selected from the LOFAR continuum surveys. The WEAVE facility is expected to have first light in February, 2020. We used a simulated dataset for this project obtained from the third operational rehearsal of WEAVE-LOFAR which was completed in June, 2019. The dataset consists of spectra for 8,878 galaxies.

The aim of the project is to obtain reliable redshifts, partcularly for high redshift sources which may have been missed by other redshifting algorithms. The cross-correlation method used in this project allows us to estimate redshifts from the emission lines of galaxies and AGNs. We generated templates of galaxies by modelling emission lines as Gaussian waveforms. The templates as well as the spectra were then re-binned in the Logarithmic-wavelength space ($\ln \lambda$). The scale chosen is such that a velocity of about 50 Km/sec shifts a feature by one bin. This is an essential step because velocity redshift is a uniform linear shift if the spectra are binned linearly with $\ln \lambda$ (Tonry & Davis 1979).

We then cross-correlate the galaxy spectra with the template which gives us the cross-correlation function (CCF) : $c(n) = \sum_m g(m) \times t(m-n)$ where $g(n)$ is the galaxy spectrum, $t(n)$ is the template and $c(n)$ has a maximum value where the template matches the spectrum. The cross-correlation values associated with redshifts are given by: $z_{ccf,n} = 10^{1.67\times10^{-4}\,\delta_{pix,n}} - 1$ where $\delta_{pix,n}$ is the shift in pixels corresponding to position n and $c(n)$ is the CCF (Baldry et al. 2014). These values along with the peaks of the cross-correlation functions are used iteratively to estimate the value of the redshift for a given spectra.

Results

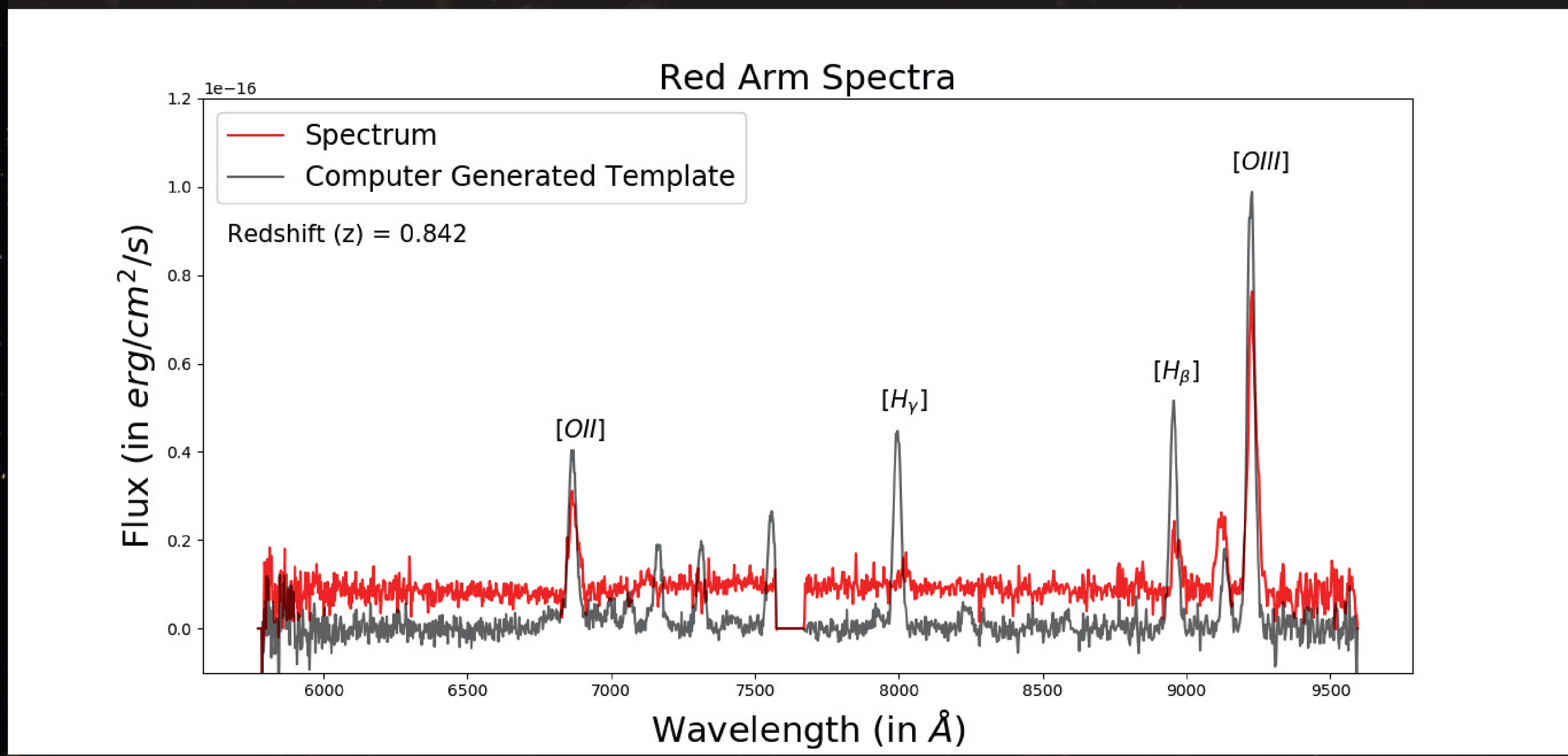

Fig.1: Shown here is the red-arm spectrum of a star-forming galaxy. The bright emission lines corresponding to [O II], H_γ, H_β and [O III] in the spectra have been marked. The computer generated template closely matches the spectrum. A cross-correlation of the spectrum against the template is carried out that gives a strong peak which is used to estimate the redshift. This is done in several iterations, and the first iteration produces a list of possible correct redshifts. Successive iterations search for redshift in a smaller range which is deduced from the previous iteration. The final pass estimates a redshift with $\Delta z < 0.003$, where $\Delta z = |z_{true} - z_{estimated}|$.

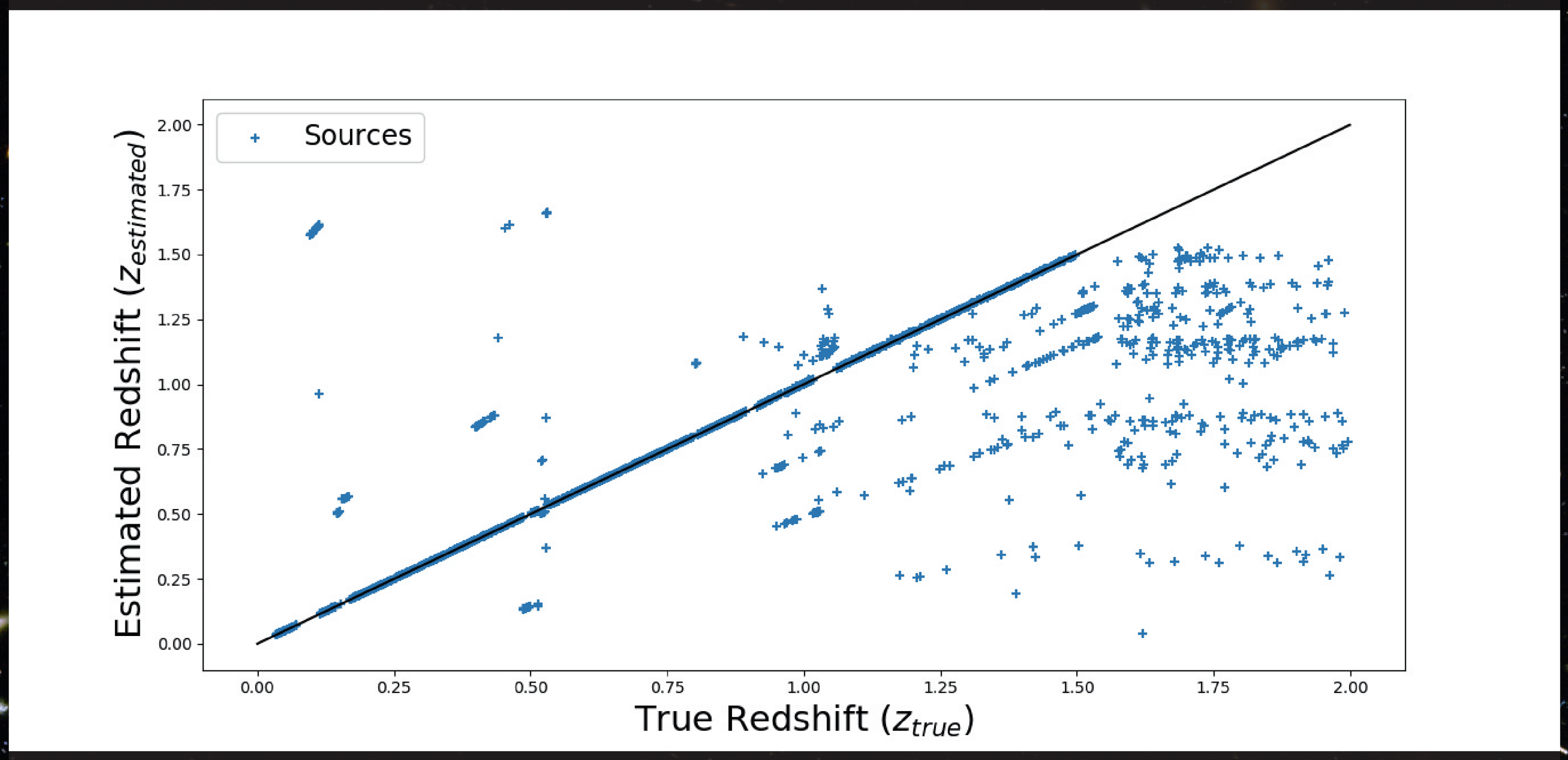

Fig.2: Shown above are the estimated redshifts plotted against the true redshifts for 2,731 galaxies. The algorithm correctly produces redshifts for 2,002 galaxies (73%) with $\Delta z < 0.003$. The CCF method successfully estimates redshifts for sources with prominent features and emission lines. The dataset consists of multiple number of observations for the sources. This allows the algorithm to obtain a high signal to noise ratio which helps to obtain strong peaks in the CCF.

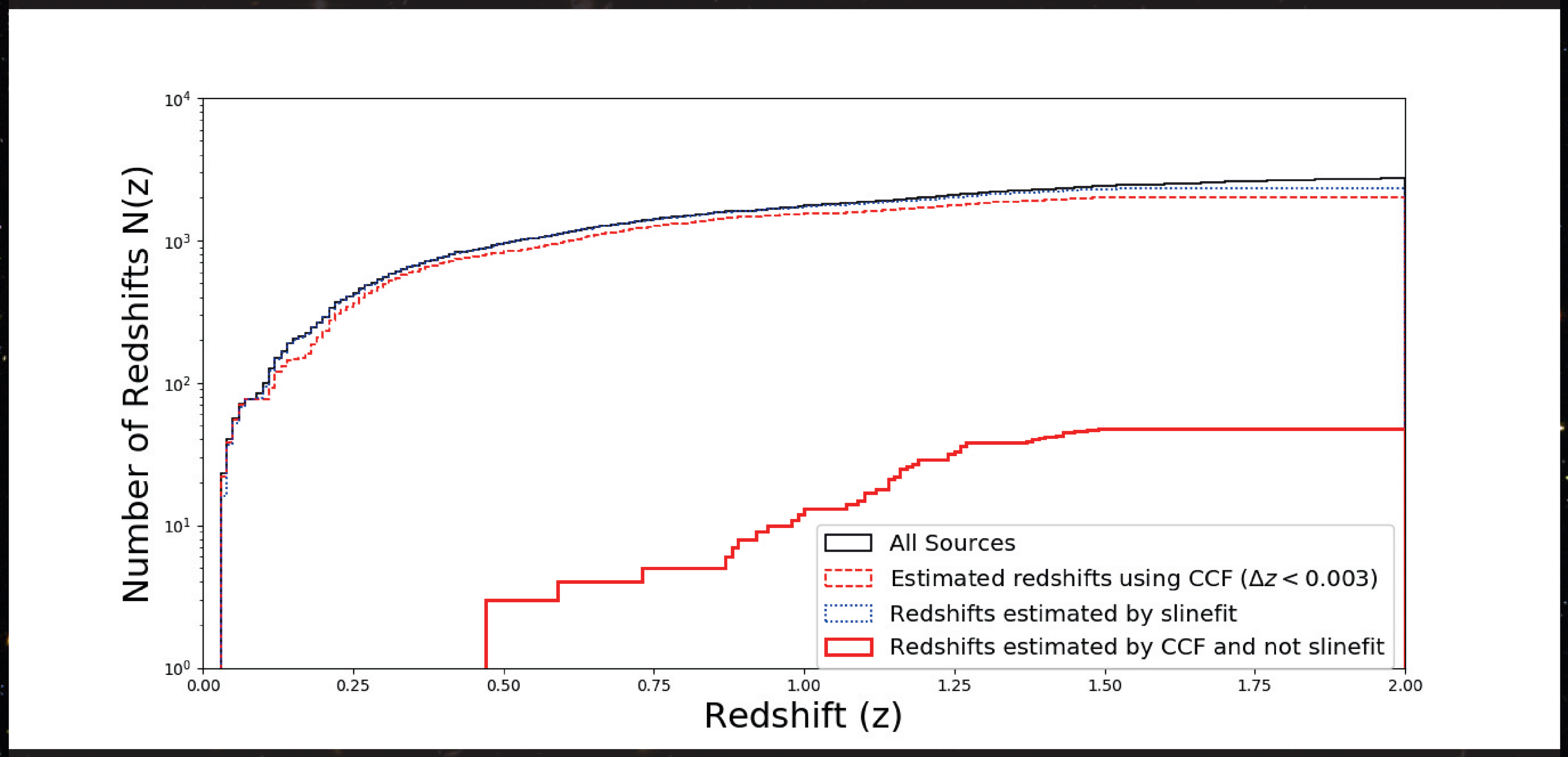

Fig.3: Cumulative frequency plot shows Number of redshifts N(z) binned uniformly for different cases as explained below. We show here the number of redshifts obtained correctly with CCF method as compared to a slinefit method which relies on fitting emission lines. The black solid line shows redshift distribution of all the 2,731 souces in the dataset sample, whereas the red-dashed line shows number of sources at each redshift bin for which redshift was estimated correctly with $\Delta z < 0.003$ using CCF method. The blue dotted line, shown here for representation, plots the number of redshifts estimated by slinefit method. The solid red line shows number of redshifts which were estimated by CCF but could not be determined correctly by slinefit method. It is interesting to note that the number of redshifts obtained accurately by CCF method increases progressively for higher redshifts. This is crucial for the success of the WEAVE-LOFAR survey because CCF method is expected to perform well for higher redshifts, where other methods like photometry and fitting may fail.

Conclusion and Future Work

In this project we focused on estimating redshifts using cross-correlation method and the algorithm was tested using a simulated dataset obtained from the third operational rehearsal of WEAVE-LOFAR. The results show that the algorithm based on CCF successfully finds redshifts for 73% of the galaxies in the dataset sample. The number of redshifts that CCF method correctly estimates increases as redshift range increases, where other methods perform poorly.

Future work on this method would aim to optimise it for sources with extremely faint emission line features at high redshifts. It would also be interesting to test how the algorithm performs using an asymmetrical profile for the Lyman-alpha line in the template. This method in conjunction with other methods, could be used by the WEAVE-LOFAR survey to find redshifts of statistically large (~ 10^6) samples of Radio-selected sources.

References:
- Smith, D. J. B., et al. (2016). The WEAVE-LOFAR Survey. sf2a.conf, 271
- Tonry, J. and Davis, M. (1979). A survey of galaxy redshifts. I - Data reduction techniques. The Astronomical Journal, 84, p.1511.
- Baldry, I., et al. (2014). Galaxy And Mass Assembly (GAMA): AUTOZ spectral redshift measurements, confidence and errors. Monthly Notices of the Royal Astronomical Society, 441(3), pp.2440-2451.

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Background Image:
Hubble Ultra Deep Field (NASA/ESA Hubble Space Telescope)