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Photometric Redshifts: A Comparison of Methods

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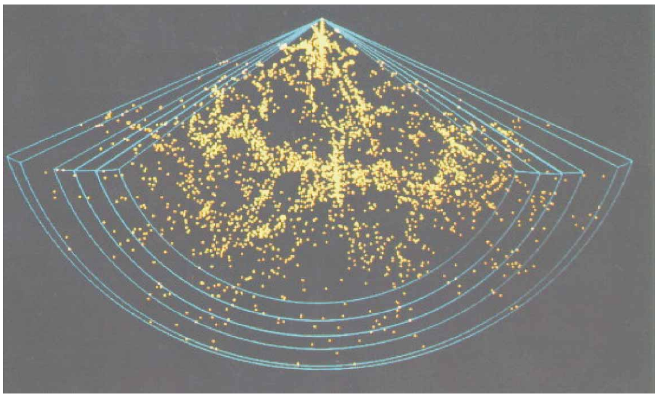
The advantages of being able to accurately extract red-shifts from photometric data is of great importance when wanting to complete large scale surveys of the night sky. In an exposure of minutes, rather than the hours needed for spectroscopy, we are able to gain colour data from a great number of astronomical sources at once. This is especially apparent with the advent of large format panoramic cameras such as the INT WFC, MegaCam at the Canada-France-Hawaii Telescope (CFHT) and, in the future, VISTA (Visible & Infrared Survey Telescope for Astronomy). If this data can then be used to accurately calculate the distribution of galaxies with red-shift, the large scale structure of the universe can be more readily determined.

Views of large scale structure have revolved around the 'Swiss cheese' analogy. Geller and Huchra (1989) showed that clusters of galaxies themselves tend to form in bubbled patterns enclosing empty regions measuring hundreds of millions of parsecs across (see Figure 1). The Swiss cheese model has also been explored by Moore et al. (1992), but consists of a 'meat-ball' distribution in a void background (see Figure 2).

There are two techniques that can be used when wanting to carry out red-shift calculations from photometric data; template fitting and the use of a training set. The first technique was initiated by Baum (1962) and later developed by Koo (1985) and Loh & Spillar (1986b). More recently Bolzonella et al. (2000) have published a very flexible method using the standard Spectral Energy Distribution fitting technique, which has been made into the publicly available code *hyperz*, (see *http://webast.ast.obs-mip.fr/hyperz/*). The second method has been developed by Connolly et al. (1995) by training a relation between galaxy colours and red-shifts via linear regression. Plotting the results of broadband photometry against red-shift showed a strong correlation of red-shift with UBRI colours up to approximately z = 0.6. Figure 3 depicts red-shift data as a function of three broadband colours. Blue dots correspond to zero red-shift galaxies, and red to a red-shift of 0.5. Each colour distinguishes red-shift intervals of approximately $\Delta z = 0.1$.

Before we continue to use photometric red-shift methods for further investigations we will compare the two techniques. In order to do this we have selected a 9 deg^2 area in the Elais N1 region. The data has been collected as part of the ING's Wide Field Survey (WFS) campaign in the Ug'r'i'z band-passes and reduced via the ING/CASU WFS pipelines (see *http://www.ast.cam.ac.uk/~wfcsur/pipeline.html*). Object catalogs have



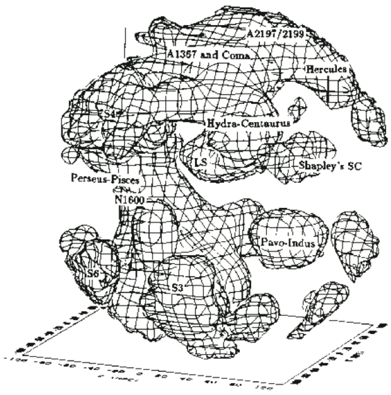


Figure 1 (left). Distribution of ~4000 galaxies in red-shift space, Geller and Huchra (1989). Figure 2 (right). Distribution of galaxies within 100 Mpc of the Milky Way, Moore et al. (1992).

been produced and formatted for use with the two methods. The method of Connolly et al. (1995) requires the use of UBRI magnitudes to which the Ug'r'i' were corrected using Fukugita et al. (1996). Magnitudes were also corrected for the effects of atmospheric extinction at the La Palma site (King, 1985). An estimation of reddening was made using Schlegel et al. (1998). The 4096×4096 pixel Lambert projection of dust in the North Galactic Pole was obtained via *ftp* to Berkeley (*ftp deep.berkeley.edu*). Using the available IDL interface, an estimation was made and averaged over the Elais region centred at RA 16 10 00 DEC +54 30 00 (J2000). E(B−V) was then converted to the required band-passes.

This same method of magnitude correction was also used for the *hyperz* code. However, a colour correction was not needed as the code allows you to map in the response of the filters used. *Hyperz* also accommodates the use of all the Ug'r'i'z wave-bands.

A simple way of testing the methods described is to compare the photometrically determined redshifts with those from direct spectroscopic measurements. Extensive searches of NED and LEDA found fifteen galaxies in the sampled Elais area with predetermined red-shifts. Once these red-shifts have been determined plots of z_{spec} against z_{phot} can be made and compared.

Galaxies exhibit a wide variety of morphological types, it's not certain that we can see all of them across the colour ranges, especially faint dwarf galaxies. Looking through the catalogs showed that more sources were present in the g' and r' bands than the U due largely to the poorer limiting magnitude reached in U. These extra sources could not be used with the Connolly method as it does not accommodate null detections. The result is a lower galaxy count (more so at the higher red-shifts). The *hyperz* method facilitates for effects such as age-metallicity links, the reddening law, flux decrements in the Lyman forest and the cosmological parameters H_0, Ω_0, Ω_Λ when building the synthetic spectra, these null detections are therefore accounted for here.

The mosaic nature of the WFC creates gaps between each chip in the array. Dithering the images or rotating the array on the sky are methods which can be used in order to remove these gaps, but these were not used for the Elais region. Our sample area includes many of these gaps which run all over the region. If it is assumed that the distribution of galaxies within these regions follow that of the hole sample then an estimation of the missing galaxies can be made.

At present we have surveyed the 9 deg^2 area using the training set method of Connolly (1995). Figure 4 shows the distribution of the galaxy red-shifts and reflects the increase of galaxies with volume and the sensitivity limit of the survey. Comparison of predetermined galaxy red-shifts with these photometric

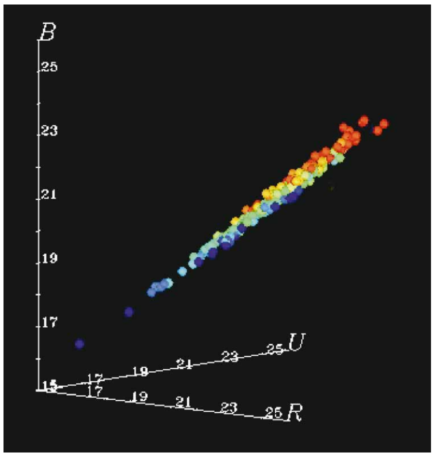


Figure 3. Three broadband colours as a function of red-shift, Connolly et al. (1995).

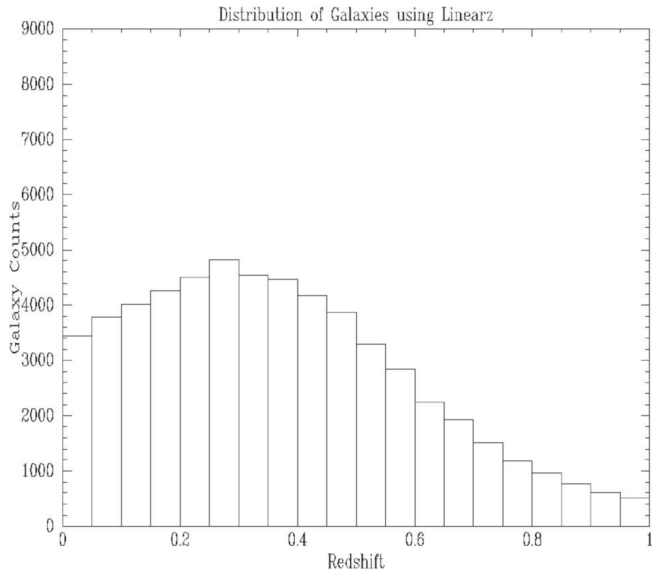


Figure 4. Distribution of galaxy red-shifts within the 9 deg^2 sampled area.

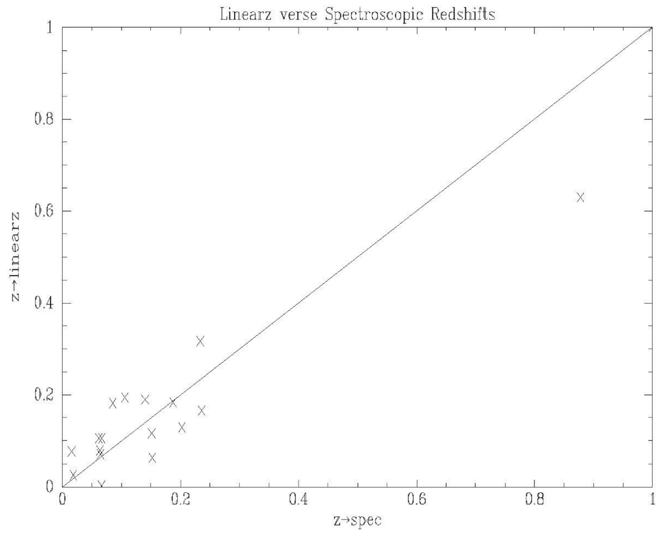


Figure 5. Plot of linear red-shifts against spectroscopic redshifts for objects in the Elais N1 region.

red-shifts (see Figure 5) suggest that the Connolly relation may need to be trained further to accommodate the different colours used. The dispersion in the fit is $\delta z=0.086$ compared to a $\delta z=0.057$ noted by Connolly et al. (1995).

In the near future we will have surveyed the entire 9 deg^2 area using both methods. Further plots of z_{spec} versus z_{phot} will show which method produces more accurate red-shift data, this method then being used to carry out red-shift surveys with INT data and to investigate areas such as the large scale structure more readily.

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