DARTH FADER: Using wavelets to obtain accurate redshifts of spectra at very low signal-to-noise

D. P. Machado¹, A. Leonard¹, J.-L. Starck¹, F. Abdalla²

¹ CEA Saclay, IRFU, Service d’Astrophysique, Bt 709 - Orme des Merisiers, 91191 Gif-Sur-Yvette CEDEX, France.
² University College London, Department of Physics & Astronomy, Kathleen Lonsdale Building, Gower Place, London, WC1E 6BT, United Kingdom.

Introduction

Accurate determination of galactic redshifts comes from the identification of key lines in their spectra. When spectra are too noisy, they can be thrown away by selecting for magnitude or signal-to-noise. We present DARTH FADER (Denoising And Randomized Estimation of redshifts) with a Fast Beam-Box method, which is a wavelet-based method for estimating galactic redshifts, and empirically isolating the continuum of a spectrum. We employ a wavelet denoising on the spectrum using a false detection rate (FDR), and counting the number of peaks in the cleaned spectrum. We choose cleansed spectra with three peaks to be good candidates since the presence of only two lines leads to an ambiguity in the estimated redshift.

Mock Catalogues

- Mock catalogues were generated using LUFFE simulation program (Amuse, et al. 1998) with 3000 top-hat filters for the template set, each in bands of 51 filters, with the 51st filter being the same as the original, well-known, redshifts and CWW-Kinney templates (Colgan, et al. 1991, Kinney, et al. 1998) used throughout.
- The filters are divided into two groups, one for 2.0 - 3.0, where the mean is estimated to be where \( \lambda = \lambda \) is a minimum, and the other for 3.0 - 4.5, corresponding to a wavelength range of 3160˚A to 31623 ˚A (3.5 to 4.5 on the log axis).
- The template set consists of 250 redshifts, including 2.5 and 3.0, and the galaxy catalogue of 2757.
- Multiple galaxy catalogues were constructed from the base set, adding wavelength independent Gaussian noise on the continuum. Multiple fixed signal-to-noise, and a single uniformly mixed signal-to-noise, catalogues were constructed spanning the range 1.0 to 4.5.

Cross-Correlation and PCA

- Darth Fader utilises a standard PCA and cross-correlation procedure, similar to that of Glazebrook, et al. 1998.
- It is possible to construct a set of orthonormal eigenimages, \( E \), from any template set, \( T \), via a PCA procedure:

\[
E_i = \frac{T - \overline{T}}{\sqrt{\sigma_i}}
\]

where \( E_i \) are the orthonormal eigenimages, \( T \) is the template set, \( \overline{T} \) is the mean of the eigenimages, and \( \sigma_i \) is the variance of the eigenimage.

- The estimate of the goodness of fit of the galaxy spectrum, \( G_i \), can be found by computing the minimum distance via a standard distance: \( \chi^2 \): giving:

\[
\chi^2 = \sum_{i=1}^{N} \left( \frac{T - \overline{T}}{\sigma_i} \right)^2
\]

- By subdividing the template set \( T \) into the eigenimage set \( E \), using the orthogonal condition between eigenimages and the properties of the convolutions theorem, we can significantly simplify this to finding the maximum of the following:

\[
\chi^2 = \sum_{i=1}^{N} \left( \sum_{j=1}^{M} \frac{E_{ij} \cdot C_{ij}}{\sigma_i} \right)^2
\]

where \( E_{ij} \) and \( C_{ij} \) represent Fourier and inverse-Fourier transforms respectively.

The \( \chi^2 \) function reaches a maximum and thus the \( \chi^2 \) is a minimum when the shift of the templates along the log-wavelength axis corresponds to the true shift of the galaxy spectrum, so that the redshift is estimated to be where \( \Delta = \Delta \), giving:

\[
\chi^2 = \frac{G_i - \overline{G_i}}{\sigma_i} \cdot \Delta = \frac{G_i - \overline{G_i}}{\sigma_i} \cdot \Delta
\]

Discussion

- We have shown DARTH FADER is a powerful tool for the improvement of redshift estimation without any prior knowledge of galactic spectra, type or morphology.

References


Acknowledgements

- The authors would like to acknowledge the support provided by the European Research Council, through grant SparseAstro (ERC-228261).

http://jstarck.free.fr/iasp.html

* Corresponding: daniel.machado@cea.fr