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MULTI-FILTER SPECTROPHOTOMETRY OF QUASAR ENVIRONMENTS

Sally E. Craven and Paul Hickson, University of British Columbia
Howard K.C. Yee, University of Toronto

Summary

A many-filter photometric technique for determining redshifts and morphological types, by fitting spectral templates to spectral energy distributions, has good potential for application in surveys. Despite success in studies performed on simulated data, the results have not been fully reliable when applied to real, low signal-to-noise data. We are investigating techniques to improve the fitting process.

Multi-filter spectrophotometry, in which photometry of images in many narrow-band filters produces a spectral energy distribution (SED), allows the redshift and type of many objects in a CCD field to be identified. Cross-correlation of spectral templates with real galaxy spectra has been successfully used to determine redshifts (e.g. Ellingson and Yee, in progress), but such methods depend on the presence of emission lines. The coarse resolution of the SEDs means that the presence of emission lines, if detected, will be poorly known. Here, we describe an alternative method by which galaxy spectral template are fit to the SEDs by minimization of errors.

The technique has immediate application in the planned survey by the University of British Columbia Liquid Mirror Telescope (LMT), a relatively inexpensive and easily constructed transit survey instrument with a set of forty narrow- and intermediate-band filters. Hogg, Hickson, and Gibson's paper in this volume describes the instrument in more detail.

Two fields were chosen for the experiment, each containing a quasar at the centre of a cluster of galaxies. The results presented in this paper are for the field around 3C 281, a quasar at z=0.602. The second cluster field in the study is that around the z=0.403 quasar PKS0812+020. Images 3.5×5 arcminutes in size were obtained at the Canada-France-Hawaii Telescope, two in each of twenty-four 100Å-wide filters. The aperture-photometry package PPP (Yee 1991, PASP 103, 396) was used to do the photometry in every filter, on each of the 247 objects in the 3C 281 field. The growth-curve algorithm assigns an appropriate aperture for photometry based on the shape of the magnitude-vs-aperture curve, and therefore the change in apparent size of the object imaged through different filters does not affect the fraction of light measured.

The morphological type and redshift for each object are estimated by finding the parameters of a model spectral energy distribution providing the best fit to the real SED. The object types are quantified in a series running from E (0.0) through Sab (1.0) and Sbc (2.0) to Im (3.0). Four real-galaxy templates were obtained from Coleman, Wu, and Weedman (1980, ApJS 43, 393). Intermediate-type templates (e.g. 1.1) are calculated by linearly interpolating between the known spectra.

Each model type, in increments of 0.1, is redshifted by amounts from 0.01 to 1.00, in steps of 0.01. At every point, the model (in log I–log ν space) has added to it a range of offsets, for each of which the fit is analyzed by calculating χ^2. The model type, redshift, and offset producing the lowest χ^2 value are assumed to correspond to the physical nature of the object. The χ^2 value is weighted according to the size of the uncertainties in the data : it is the sum over all the points in the SED of $(\log I_{model} - \log I_{data})^2/\sigma^2$. However, χ^2 would better represent the nature of the fit if calculated in the linear domain, rather than the log; this change will be instituted shortly. The solid lines drawn through the SEDs in the figure are the best-fit models. The uncertainties, indicated by the error bars, include contributions from possible missed light, zero-point uncertainty, Galactic and atmospheric extinction, and the PPP error which is due to sky noise in the photometry aperture.

At present, we cannot place much confidence in the redshifts and classifications obtained by this method. We compare our results with measured redshifts for twelve objects in this field, published by Ellingson, Yee, and Green (1991, ApJ 378, 476; hereafter EYG91), and find that only six of the redshifts derived by template-fitting correspond to the published values. Even then, some of the fits have poor χ^2 values, and their dubious appearance prompts caution!

Problems in the type/redshift identification arise from three sources: limited template range, the fitting technique, and the data quality. At this stage of the project only four galaxy template types, and models interpolated between them, are compared to the SEDs. Hence, active galaxies, QSOs, and stars are not represented by the template set, and are forced to fit a galaxy model. A priority in the near future is to incorporate a more physically complete range of galaxy templates into the fitting program.

The χ^2-minimizing technique used to fit the templates to the SEDs can take into account the uncertainties in the data points, but does not exclude (or otherwise acknowledge) sporadic data points. Especially in the fainter objects, significant errors in the flux values are common due to low signal-to-noise and a lack of compensation for cosmetic flaws in the CCD. We intend to develop a fit-independent means of identifying these outliers; if this is unsuccessful, we will replace the χ^2 algorithm with a more robust statistical fitting technique.

The data quality is the limiting factor in the accuracy of the classification technique. The outliers and scatter typical of most of the SEDs may be a result of the low brightnesses of many of the objects, which cause them to be easily contaminated by sky noise. (Typical signal-to-noise values range from 0.1 to 10 in blue-end filters, 1.0 to 15 in the red end, with a few higher values for bright objects.) In addition, the photometry package does not compensate for CCD defects and cosmic rays, which will affect the flux in some objects.

In a modelling analysis, the problems described above can be avoided. Callaghan, Gibson, and Hickson (in this volume) present a discussion of the accuracy of the technique. They use idealized Gaussian filters with the same central wavelengths as the filter set used here.

This technique will be used in analysing the data acquired by the Liquid Mirror Telescope. However, that survey has both wider and better- sampled wavelength coverage, and a higher-quality filter set. SEDs from the survey should be of much better quality than the ones shown here, and the classification results will be correspondingly better.

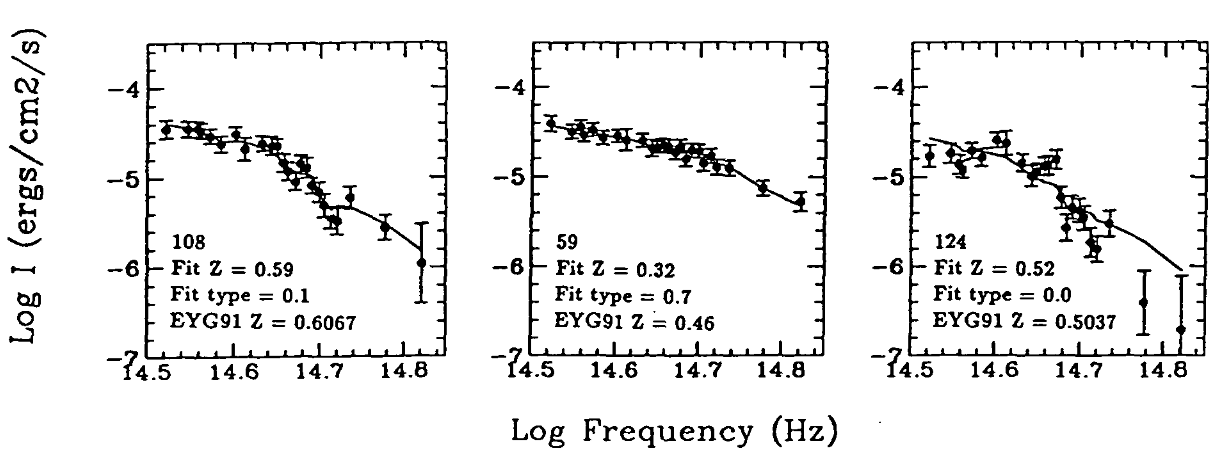

Figure: Examples of spectral energy distributions with their best-fitting templates overplotted. The vertical axis is log intensity (in ergs $cm^{-2}s^{-1}Hz^{-1}$) and the horizontal axis is log frequency (in Hz). Notice that the fit to object 59 seems clean, but the redshift is wrong, while 108 has the right redshift but a poor fit.