Spectral Reduction Software for the DEEP2 Redshift Survey

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Abstract. The DEEP2/DEIMOS redshift survey, which will begin observing in the Spring of 2002, will gather high quality spectra on $\sim 60000$ galaxies in order to study the evolution of the properties and large scale clustering of galaxies at $z \approx 1$.

The data rate from DEIMOS will be in excess of 1 Gbyte/hour, and it is therefore imperative to employ completely automated data reduction techniques to manage the analysis. We here describe aspects of our data pipeline, which will make extensive use of B-splines for the sky-subtraction stage and for the combination of multiple frames.

1 Spectral Reduction Strategy

The Keck II Deep Imaging Multi-Object Spectrograph (DEIMOS) is intended for imaging and multi-slit spectroscopy over a field of view that is approximately a rectangle of size 16' by 5' and over the wavelength range 0.42-1 $\mu$m. With its focal plane mask allowing slitlets spectroscopy for $\sim 100-150$ objects, DEIMOS is optimally designed for large surveys of faint objects. The initial use of DEIMOS will be largely to undertake a massive redshift survey of $\sim 60,000$ $z \approx 1$ galaxies, the DEEP2 survey [1].

The technical complexity of the reductions and the shear volume of data force us to a rather new approach to spectral data reduction. Working closely with the SDSS team, we are developing a dedicated, fully automatic data reduction package based on the IDL codes of Schlegel, Burles, and Finkbeiner.

1.1 Spectral Tracing

The DEIMOS mosaic imager is an 8K by 8K pixel camera composed of 8 individually mounted 2K by 4K CCDs manufactured by MIT Lincoln Laboratory. The pixel size is 15 $\mu$m. The DEIMOS CCDs are thick, high resistivity devices, with enhanced QE in the near-IR and much reduced fringing compared to thinner chips. In contrast to the VLT/VIMOS design, DEIMOS will have smaller multiplexing but many more spectral pixels per target, and there will not be multiple objects within a given row of data. The large number of pixels in the dispersion direction (8K) allows high resolution with substantial spectral range, i.e. a wide redshift interval coverage, while the spatial extension allow us to cover 16' of sky and a large multiplexing capability.

The spectrum of each object will be dispersed across 2 CCDs separated by a gap whose size is a polynomial function of the position along the spatial direction. We have developed a series of fast algorithms to trace the spectra across the 2 CCDs, align and rectify them and fit the gap size with sub pixel precision at each trace position. Based on the traces of the edges of the curved slitlet spectra over the CCD frame, the data for individual slitlets is shifted by whole pixels in the spatial direction to produce rectangular spectra. We next perform a non linear wavelength solution fit to calibrating arc lamps using the formula

$$\lambda(x) = a_j \cdot L^j \left[ x + G(y) \theta \left( \frac{x}{4096 + G(y)} \right) \right]$$

where $L^j(u)$ are Legendre polynomials of order j, x is the pixel position along the dispersion direction, $G(y)$ is the unknown gap at position y along the spatial direction and $\theta$ is the Heaviside theta function.
A standard Hg-Ne-Ar lamp, dispersed by a 900 l/mm grating can be fit with a scatter of 0.01 Å and gives the functional form of gap function G. Since the gaps will not change with time, the information for G(y) will be stored in a table rather than fit from individual frames.

1.2 Sky Subtraction

Studies of faint, high-redshift galaxies rely on our ability to remove very strong night sky airglow lines which overlie the spectra of these faint objects. This is crucial at high redshifts, since the intensity and frequency of OH night sky lines increases in the near-IR and can readily swamp emission lines from faint target galaxies, such as a redshifted OII doublet (3727 Å).

The DEIMOS camera coupled with the 900 l/mm grating and slits of width 0.75" will allow us to observe in a high resolution operational mode, $R \equiv \lambda/\Delta\lambda = 3700$. This planned spectral resolution (80km/s) is needed for resolving the OII doublet (giving confidence to the redshift determination even if no other features are observed), minimizing sky lines spectral contamination, and optimizing atmospheric subtraction. With this high spectral purity, we intend to use tilted slits to follow the major axis and to map rotation curves of many of the target galaxies, thus leading to seriously tilted night sky lines in the 2-d image.

Sky subtraction can be a very critical step in the reduction of long slit spectra with the main problems being uncorrected fringing and the curvature of the lines along the slit. Although one may intuitively tend to subtract the sky spectrum still in pixel space in order to avoid the problems inherent to non-linear rebinning, experience shows that a proper wavelength calibration can remove the curvature of the sky lines to a high degree of accuracy (one should aim for 0.1 pixels rms). The standard approach to sky subtraction consists of a linear interpolation of the sky modal values of the two sky frames which immediately bracket the object frame. But such an approach requires considerable extra slit-length for each object, reducing the allowed multiplexing of the targets. Furthermore, the analysis of data from tilted slits is greatly complicated in such a scheme.

An alternative optimal method consists in processing background spectral characteristics with B-spline functions. This is a relatively new fitting technique, widely applied in CAD systems in which a set of piecewise polynomial curves are used to approximate continuum data. Here the key-word is approximation, which means that the B-splines curves pass close to a set of data points without passing exactly through them. B-spline curves are represented in parametric notation by the following
expansion

\[ P(t) = \sum_{i}^{n} N_{i,k}P_{i} \]

where \( N \) is the functional basis and \( P_{i} \) are \( n \) data points. We can interpret it as a normal functional expansion but instead of using Legendre or Chebishev orthonormal polynomials we use a set of more flexible functions such as piecewise cubic splines. These functions are uniquely determined (as in a standard interpolative scheme) once we specify an order of fit \( k \) and a set of control points (in the domain of the parameter \( t \)) known as knots.

B-splines have many attractive properties that make them superior to more conventional basis sets in the description of continuum data, the main advantage residing in their local nature. Any control point influences the shape of the curve close to it and, with a suitable spacing between knots, we can control the elasticity of the fit in such a way to improve the stability of the reconstruction in noisy image environments. In this way we can automatically reject interlopers, image defects or cosmic rays polluting the sky determination. Moreover the convergence to solution is always guaranteed by the intrinsic interpolative nature of the method. The method requires that we know the wavelength of every pixel, but there is no rebinning of the sky data, and tilted slits or tilted spectral lines present no additional complication. The B-spline fitting can be used to generate a “supersky” spectrum which can be applied to different slitlets. The same technology is ideal for the averaging of 1-d extracted spectra, without the need to first remove cosmic rays or to align the spectra in wavelength space.

We simulated the performance of the B-spline method by using arc lamp spectra to reproduce the night sky lines. Even if the real sky subtraction accuracy is difficult to gauge with laboratory images, the residual counts in our simulated sky-subtracted spectra (shown in fig. 1) provide a good estimate of the goodness of the method. With a sufficient knot density, we are able to reproduce the spectrum of the arc lamp to high precision, and we find that the residuals of the spectrum from the B-spline average are consistent with Poisson fluctuations, even over the regions of nearly saturated emission lines, as shown in figure 1b.

1.3 2D Wavelength Solution

Thanks to this capability of automatically removing the most deviating points from the underlying signal, the B-spline procedure can also be optimally applied for determining the full wavelength calibration of a 2D extracted spectrum. The 2D pixel-to-wavelength mapping is needed in order to apply the sky subtraction strategy described in §1.2.

To obtain this information we exploit the simple fact that the wavelength scale \( \lambda = \lambda(x, y_{c}, G(y_{c})) \), established for the central reference row \( y_{c} \) of the comparison spectra (arc lamp), allows us to unambiguously label, with tabulated wavelengths, every other peak position \( (x_{i}, y_{j}) \) of the spectra.

We then fit at once the whole comparison spectra (i.e. the data set \( \lambda = \lambda(x_{i}, y_{j}) \)) with a 2-dimensional B-spline generating the full wavelength solution for each pixel in a fast way, virtually insensitive to bad pixels or outliers.

The Keck/DEIMOS survey is a collaborative project among astronomers at UC, Caltech and the Univ. of Hawaii. The team intends to share all results with the public and to put the spectra online in a timely manner. Details of the project can be found at the URL [http://astro/berkeley.edu/deep/](http://astro/berkeley.edu/deep/)

References

[1] Davis, M., Newman, J. A., Faber, S. A., & Phillips, A. C., 2000 in Proc. of the ESO/ECF/STSCI workshop on Deep Fields, (Garching, Edition Springer), [astro-ph/0012189](http://astro-ph/0012189)