Area Spectroscopy and Correction for Differential Atmospheric Refraction

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Abstract

Spectroscopic mapping is a powerful technique for obtaining spectra of extended objects. A limitation is imposed by changes in atmospheric differential refraction during the course of an observation due to the varying zenith distance of the observed source. A software technique is described whereby the data can be corrected for the effects of differential atmospheric refraction.

1 Introduction

Spectroscopic mapping at low to intermediate spectral resolution of extended objects can be achieved using a grid of closely spaced fibres feeding a spectrograph, by stepping or scanning a spectrograph slit or with a tunable narrow band filter camera. At higher spectral resolution a stepped imaging Fabry Pérot instrument (e.g. TAURUS) can be employed. The aim of the methods is identical - to map the emission line, absorption line or continuum variations over an extended object. A reduction technique to be applied to the slit scanning data will be discussed but it has general applicability to all spectroscopic mapping methods.

Examples of the slit scanning technique are provided by the only implementation to date, that of ASPECT on the Anglo Australian Telescope (AAT). ASPECT (**A**rea **SPECT**roscopy) is a software package for coordinating telescope movement and detector acquisition of long slit spectra. ASPECT utilises the IPCS (Image Photon Counting System) as detector. Full details of ASPECT are provided in Clark et al., [1]. ASPECT has been successfully used to map the line emission in supernova remanants [1] and for absorption line mapping of an elliptical galaxy [7]. The emission from HII regions in a spiral arm has been mapped by Roy and Walsh [5] and the variation of abundances have been studied in a starburst galaxy by Walsh and Roy [6]. In addition the velocity field of a planetary nebula has been mapped by Clayton [2].

The ASPECT technique need not be restricted to photon counting detectors, although their fast readout make slit scanning (i.e. multiple exposures at each slit position in a map) feasible. The method can be extended to use CCD's as detectors if the sky transparency on the object can be monitored during the exposure. In the data reduction each long slit spectrum can be rectified for the cumulative changes in atmospheric transmission during the exposure.

Since the total observing time is divided between a number of slit positions, then the demands for high signal-to-noise data require long exposure times. Over an extended period the observed

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airmass changes and hence the amount of atmospheric refraction. Since the atmospheric refraction is wavelength dependent, this leads to differential chromatic shifts during the observation. If line ratio maps between emission lines which are well separated in wavelength are required, then the presence of differential chromatic atmospheric refraction will imply that pixel by pixel division of images does not produce accurately cospatial ratios. A method is outlined whereby the effects of differential atmospheric refraction can be corrected in software during the data reduction process, thus allowing the production of accurate line ratio maps.

2 The Observational Data

The data produced by an ASPECT observation consists of a series of two-dimensional (long slit) spectra at a number of slit positions, normally parallel to one another. The pixel size of the detector defines the map pixel size along the slit (x) and the separation of the slit widths the y pixel size. These data can be assembled into a cube consisting of two spatial dimensions (x and y) and one wavelength (z) dimension. This data cube can then be processed in different ways. The spectrum of a small region can be formed by coadding a range of x and y, or a map of the source in an emission line, for example, can be formed by coadding a range of wavelengths (see for example Roy and Walsh [5]). In discussing the effects of differential atmospheric refraction and its correction it is convenient to consider the data as made up of a series of monochromatic images of the source. The effect of differential atmospheric refraction is then to shift each monochromatic image by an amount dependent on the zenith distance (ZD) and the wavelength.

Figure 1 shows the effect of differential atmospheric refraction in terms of the displacement between two wavelengths, 3727Å, the mean wavelength of the [O II]3726,3729Å doublet, and 6723Å, the mean wavelength of the [S II]6716,6731Å doublet. In an ASPECT cube this is just the shift between the [O II] and [S II] images (viz. slices at these wavelengths). Thus if one observes a source at a ZD above 40^o the shift can be larger than typical seeing of $\sim$1 arcsecond. If the pixel size of the ASPECT map were 1.5 arcseconds then the [O II] / [S II] line ratio map made at a ZD of $\geq 40^o$ would produce erroneous line ratios. In particular if the line ratios were changing rapidly with position over the source then an incorrect interpretation would be placed on the data. It is clear from Figure 1 that the period over which the data is taken must not be too long otherwise the change in the refraction with wavelength will smear the images. Some compromise between exposure time and the ZD of the observation needs to be made: at zenith distances $\leq 40^o$ exposure times should be $\leq$ 1 hour, whilst at larger zenith distances they need to be less if the imaging is not to be degraded. These limitations depend of course on the wavelength range under observation. Thus the observing programme needs to be split into blocks whose duration depends on zenith distance. The only remaining effect which can then degrade the data is seeing variations during the total period of the observation.

3 Correction Procedure

Each individual slit spectrum composing the ASPECT data is wavelength calibrated in the usual way from an exposure to a comparison lamp (e.g. Cu-Ar). The wavelength calibrated slit spectra are then assembled into a cube (x,y,λ) comprising data taken over a limited range of ZD. The mean ZD over this exposure then serves to compute the amount of atmospheric refraction.

The effect of atmosperic refraction on the data cube can be calculated from the properties of the atmosphere at the observing site. The method of Hohenkerk [4] was used. The observatory altitute, ambient temperature, atmospheric pressure and relative humidity are employed to calculate the expected refraction as a function of wavelength. The subroutine SLA_REFRO from the SLALIB

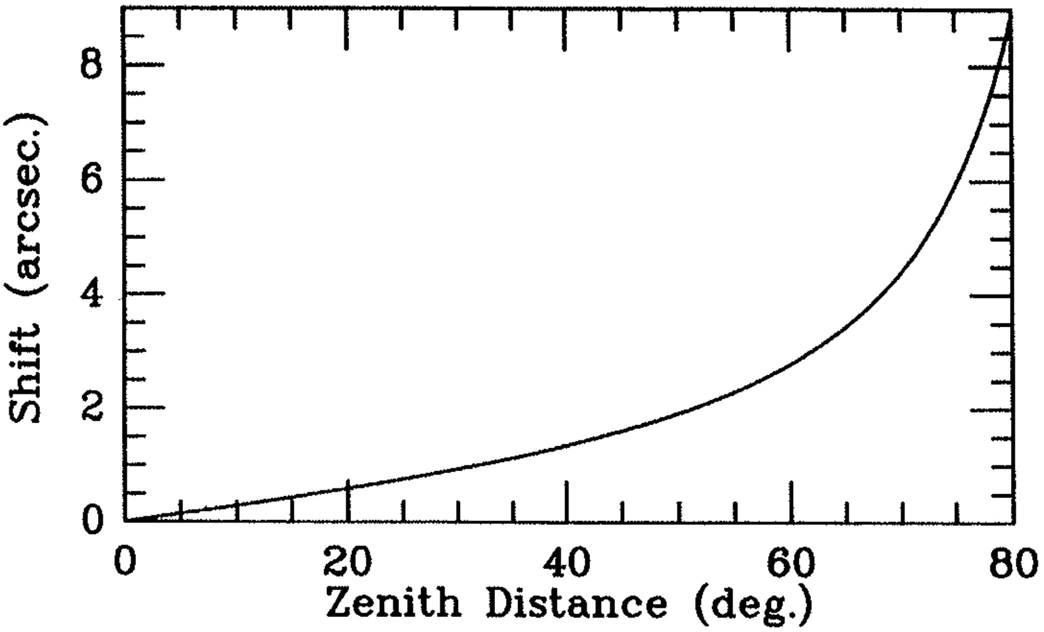

Figure 1: The observed image shift in arcseconds between 3727Å and 6723Å due to atmosperic refraction is shown as a function of observed zenith distance

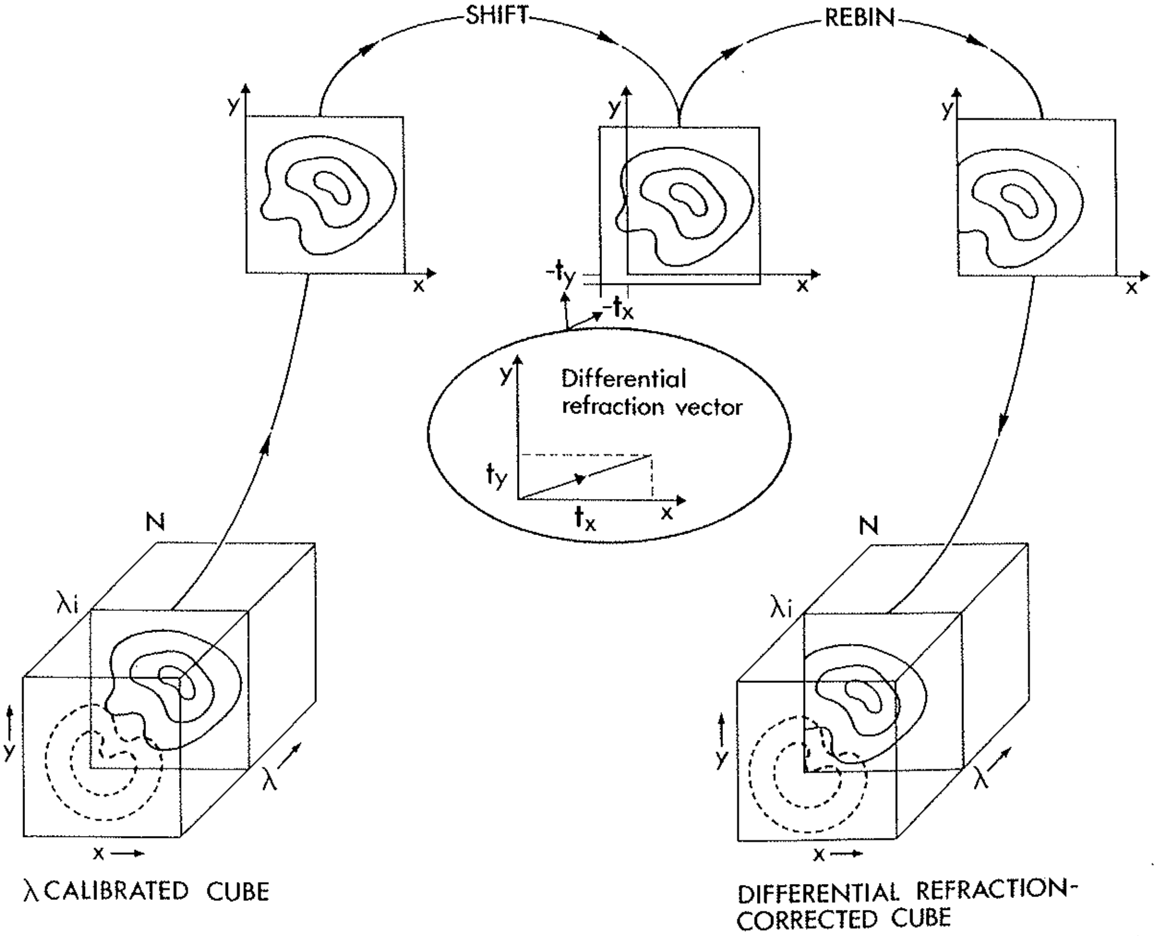

Figure 2: A diagrammatic representation of the correction of a data cube for the effects of differential atmospheric refraction.

subroutine library, written by P. T. Wallace of STARLINK was used. The direction of atmospheric refraction is the parallactic angle, perpendicular to the horizon (see Fillippenko [3]).

The main steps in the algorithm are as follows:

1. read the i th slice, wavelength λ_i, (i = 1,N) from the data cube
2. calculate the shift, Δt, in arcseconds between the i th slice and some reference slice (wavelength λ_r) due to atmospheric refraction between the two wavelengths at the observed ZD
3. from the orientation of the slits on the sky, the parallactic angle and the x and y pixel size of the data resolve the shift along, t_x, and perpendicular, t_y, to the x and y directions
4. shift the i th slice by $-t_x$ and $-t_y$
5. rebin the slice onto the reference slice
6. repeat steps 1 to 5 for all N (x,y) slices in the data cube.

The rebinning is done by fitting a two-dimensional parabola to the eight local pixels then using sub-pixel interpolation before resampling onto the reference slice. Figure 2 shows a schematic representation of the main steps in the correction procedure. The time taken depends critically on the sub-pixel interpolation applied. The greater the interpolation the better is the flux conservation. In test, a cube of 1650 λ slices, each 53 pixels (along the slit) and 10 pixels in the slit scan direction (perpendicular to the slit), was corrected in 1.3 CPU hours on a VAX8600 with 10 by 10 sub-pixel interpolation.

The atmospheric correction procedure is seperately performed on each data cube taken at a range of ZD. All data cubes can then be corrected for atmospheric extinction and coadded to form the final cube. Subsequent data reduction steps, such as absolute flux calibration using spectra of spectrophotometric standard stars, can then proceed as in normal spectroscopic reduction. As a result of the correction procedure some data will be lost from the edges of the map, the amount depending on the observed ZD and wavelength.

Some consideration needs to be given to the choice of the reference wavelength, λ_r. Obviously the λ_r slices from each cube must align spatially. If not, the coaddition of the refraction-corrected cubes will degrade any improvement in spatial correspondence. It is desirable that the reference wavelength be that of the autoguider, so that there are no shifts due to differential refraction between the reference slices from each cube. The spatial correspondence between the reference slices for each cube can of course be checked by eye.

4 Conclusion

A method is outlined whereby spectroscopic mapping data can be corrected for the effects of differential atmospheric refraction post facto in software. The only limitation this method places on the observed data is that it must be taken in short exposures with a restricted range of ZD. The correction procedure can be incorporated into the standard data reduction process. Substantial improvements in the accuracy of line ratio maps for lines well seperated in wavelength can be achieved.

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