Subject: Future Newsletter Article

<u>Optical Spectroscopy Learns the Nod-&-Shuffle</u>

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Sky subtraction is one of the major limitations to faint-object spectroscopy, especially at wavelengths where OH emission lines begin to dominate the sky spectrum (lambda > 6500A). The `Nod and Shuffle' observing mode, pioneered by K. Glazebrook and J. Bland-Hawthorn at the AAO,
provides the ability of approaching the shot noise limit for spectroscopy by greatly improving the sky subtraction over traditional techniques. The nod and shuffle technique has now been implemented at the KPNO 4m, where it is available for use with the T2KB and LB1A CCDs on the RC Spectrograph in a shared risk mode during semester 2001B.

The nod and shuffle technique is described in detail by Glazebrook and Bland-Hawthorn (2001) and interested readers are directed to this paper for a thorough discussion of the technique's pros and cons. In brief, the technique involves measuring the sky and object spectra quasi-simultaneously by offsetting (i.e, `nodding') the telescope between object and sky positions while synchronously shifting (`shuffling') the charge on the CCD between the illuminated region and storage buffers (i.e., the unilluminated parts of the CCD). Since the charge can be `shuffled' quickly and non-destructively, many short observations of object and sky spectra can be recorded alternately, thus allowing the observer to sample the sky on timescales short enough to follow its variations. Moreover, the technique results in both object and sky spectra being recorded on the same pixels, through the same slitlets, and through the same optical path. This results in identical slit variations for both sky and object spectra enabling a better sky subtraction than possible by traditional interpolation techniques.

The penalty in using this mode is twofold: the noise in the sky estimate for each row is increased by sqrt(2), and the observing time overhead is larger due to the extra time spent observing sky as well as the time spent nodding the telescope. However, the technique allows the observer to fill a slitmask with a large number of small slitlets, or, alternatively, observe large extended objects without being limited by sky subtraction errors. In the multislit mode, the gain in the number of objects per mask and the improvement in sky subtraction jointly outweigh the loss due to the observing overheads and the larger sky noise (see Glazebrook and Bland-Hawthorn 2001 for details).

On the KPNO 4m RC spectrograph, the nod and shuffle observing mode is available with the T2KB and LB1A CCDs. The T2KB CCD is more than 3 times larger than the field of view of RC Spectrograph, and the full field is therefore available to the nod and shuffle mode. Hence, in principle, the 312 arcsec diameter slitmask can accomodate as many as 50 3.0" long slitlets with the minimum recommended 0.4mm (2.65") inter-slit spacing. Note that the slitlet lengths need only be the size of an object (or its seeing profile) in the nod and shuffle mode.

The LB1A CCD which is currently available in shared risk mode with the RC spectrograph (see `Red Hot CCDs at KPNO!' in this Newsletter) has a small format (1980x800) which requires a reduction in the number of simultaneously targetted objects. The observer can either use a FOV of 110 arcsec and densely pack slitlets as described above, or alternately use the full FOV of 312 arcsec, and leave dead space between slitlets for the storage region. Hence, although LB1A will provide far better red sensitivity than T2KB, the user will only be able to target between one-third and half the number of objects.

The Nod and shuffle technique is also useful for spectroscopy of large extended objects (i.e., objects which fill a large fraction of the spectroscopic slit) where accurate sky subtraction is desired.

At the time of this writing, the time overhead incurred by using this mode is large, since the overhead added by each telescope offset and guider acquisition is 15 seconds. Hence, a 30 min exposure on target, subdivided into 60 second integrations, takes a total of 75 minutes (not including the 2 minute readout time of the CCD). We are currently investigating ways of reducing this overhead and will also implement the Nod and Shuffle mode with the new KPNO 4m guider.

We are offering this observing mode on a shared risk basis for the 2001B semester. Users interested in using this mode should contact Arjun Dey (dey@noao.edu) prior to their runs for the latest information.

Figures:

Figure 1: The upper panel shows a subsection of the raw CCD frame produced by the Nod-and-Shuffle mode. The lower panel shows the result of simply shifting the image by the shuffle offset and subtracting the shifted version from the original.

Figure 2: The upper panel shows a single row of the raw CCD frame in a region of strong OH telluric emission (approx. 7180 - 8340 A). The lower panel shows the same region in the (unflatfielded) sky subtracted spectrum. The \sqrt{2} Poisson noise from the sky is overplotted in red.

Reference

Glazebrook, K. and Bland-Hawthorn, J., 2000, PASP, in press (astro-ph/0011104)