Title : **Dithering observations**

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1 Introduction

Warm pixels may be a source of additional non-statistical noise, which may become a limiting factor on signal-to-noise ratio when going for long integration times. Cooling of the CCDs has been done thus the potential for further decreasing the number of warm and hot pixels is virtually absent. Increase in radition damage with time may increase the number of warm pixels again. Careful adjusting the level of the acceptance threshold may improve the situation slightly.

However, the only sure way to decrease noise further during long integration times is to spread the warm pixels over more wavelength bins. In other words: slightly change the pointing with respect to the source during the observation. This procedure is called "dithering". This will more evenly divide systematic errors over the spectrum. Local systematic errors may strongly influency narrow line features. This also has the advantage that gaps due to bad pixels and CCD boundaries will be covered.

Potentially, dithering will also smear-out features due to the fixed pattern noise, improving the spectrum quality. However, it was concluded before that the fixed pattern noise is not a serious problem (RGS-SRON-CAL-ME-03/CV1).

A test observation was carried out to test the potential of this observational mode.

2 Data and reduction

A dithered observation was carried out on Mkn421 in orbit 640. Observation 0158970701 took 50 Ks. The pointing history of the observation is shown in fig 1.

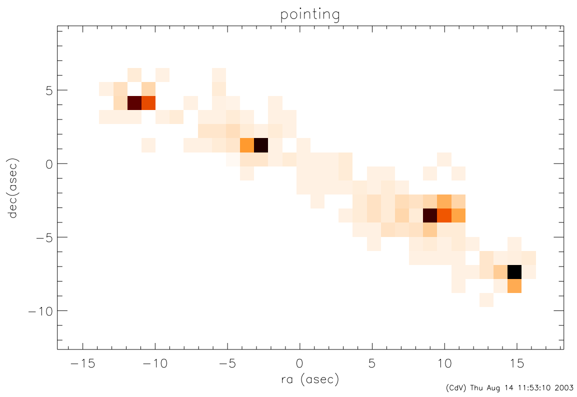

Figure 1: History of pointing during the Mkn421 observtion. The plot shows relative positions. The color indicates the time the telescope spent on that position. The total dither pattern extends over about 30 arcseconds

As can be seen the total dither pattern extends over 30 arcseconds, which is equivalent to 12 (3×3 OCB) pixels, or about 4 resolution elements. At such small offsets the response is not affected.

This observation was processed with the standard SAS. The result data were fitted in XSPEC with a single absorbed power law spectrum. The absorption was frozen to the ‘standard’ value for Mkn421 of $N_{\rm H} = 1.66 \times 10^{20}$ cm^{-2}.

The SAS however will flag events from CCD area’s which overlap during an observation as “dubious”. Clearly, for dithered observations areas will overlap, but these areas still have high quality data. For this reason the SAS (rgsproc) processing parameters were set to:

$$\mathrm{rejflags} = \text{"BAD\_SHAPE ON\_BADPIX"}\ \mathrm{flxquality} = \text{"0 2"}\ \mathrm{edgechannels} = 0$$

to keep events on and next to chip edges and make proper fluxed spectra. In addition the often used “ignore bad” in XSPEC cannot be used, since this will ignore the “dubious” flagged areas, which are the overlap areas.

For comparison the same dataset was processed as non-dithered data. For this purpose the attitude history file was altered to simulate that the pointing was stable on one fixed position. The SAS and XSPEC processing was done identical to the dithered data. Since Mkn421 has a very smooth power law spectrum without clear features (except the interstellar oxygen absorption) the dithered and non-dithered spectrum fits can be compared directly in terms of noise and systematic errors.

3 Analysis

Fig 2 and 3 show the dithered and non-dithered XSPEC spectra fits of the parts of the spectrum around the oxygen absorption features. As can be seen in the dithered case all gaps due to CCD boundaries and bad pixels have been nicely covered and the computed exposure nicely follows the data. This means the SAS can properly handle dithered observations. In the non-dithered case the gaps due to CCD boundaries and bad pixels remain and any possible spectral features on these places would be lost.

In the spectra two narrow absorption features can be recognized: the 1s-2p line of interstellar neutral Oxygen at 23.5 Å and the local intergalactic Oxygen-VII absorption at 21.6 Å. Because the interstellar neutral oxygen edge in the XPSEC model is not at quite the proper place the absorption around the 1s-2p line in the fit residues is somewhat currupted and does not show as narrow as it should be.

To judge the improvement in quality of the spectra due to dithering we concentrate on the smooth parts of the spectrum outside the absorption features.

It can be seen that some ‘outliers’ present in the non-dithered fit residues (e.g. around 19.4 and 26.1 Å) have been significantly reduced in the dither spectra. These systematic anomalies due to warm pixels have been smeared out in the dither spectra and their impact is thus reduced. This behaviour can be analyzed in a more systematic way.

In fig. 4 a histogram is made of the fit residues of the total spetrum (8 - 38 Å). To exclude deviations of a proper powerlaw behaviour and larger scale errors in the response, the residues are extracted from a ‘local’ average over a width of 9 pixels. We thus concentrate only on the high frequency ‘noise’ in the spectra.

It shows in fig 4 that the non-dither data suffer from somewhat more pronounced tails in the distribution. There are some ‘outliers’, which are absent in the dithered data. This is also expressed in the χ^2 of the

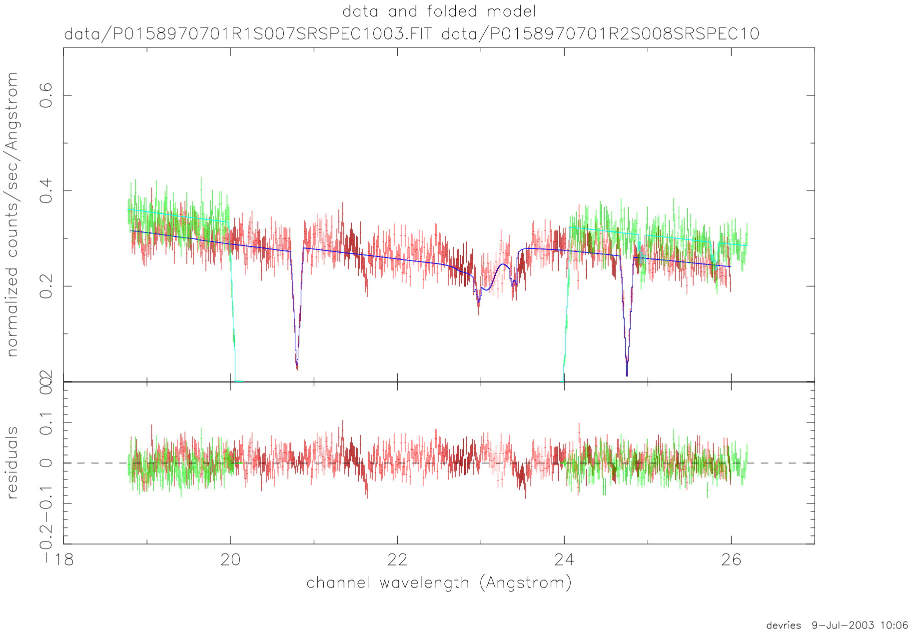

Figure 2: XSPEC fit of the dithered observation. As can be seen, potential gaps due to bad pixels and CCD boundaries are nicely filled in.

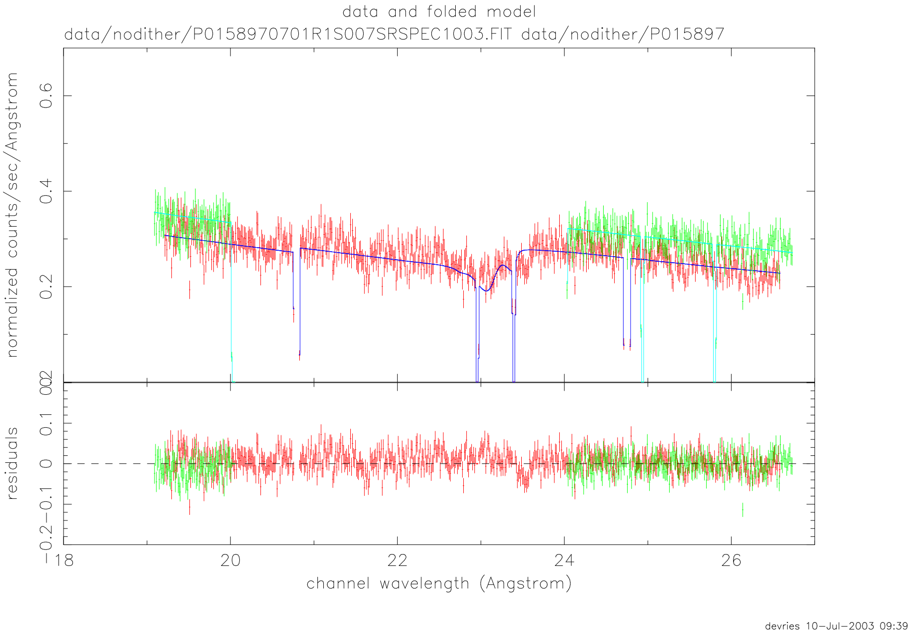

Figure 3: XSPEC fit of the non-dithered observation. Gaps do show due to to bad pixels and CCD boundaries.

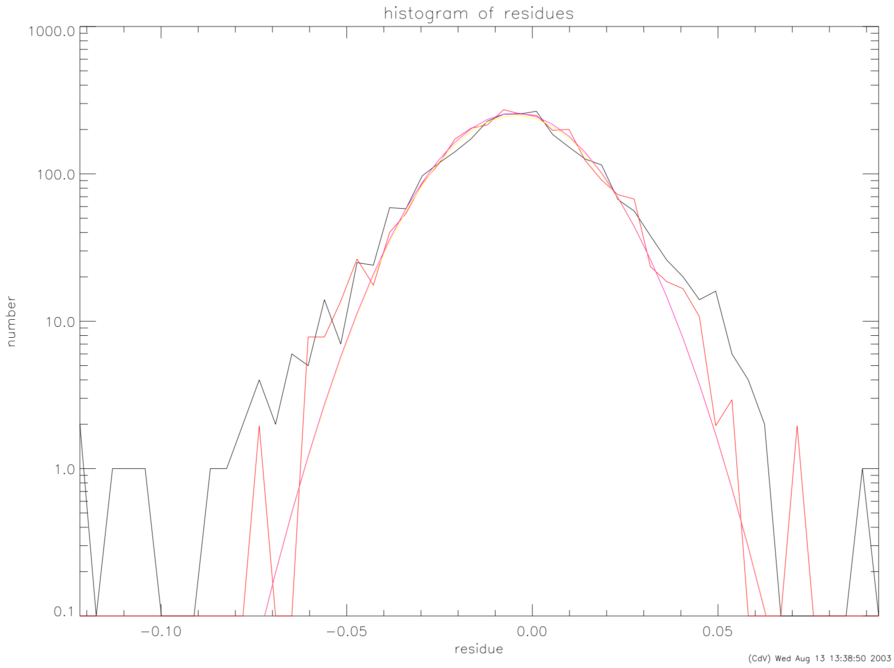

Figure 4: Histogram of fit residues on the total smoothed spectrum (8 - 38 Å.) Black line is the non-dither data while the red line is the dithered observation. The yellow and purple lines (which almost overlap) are gaussian fits to the respective data. As can be seen the non-dither data has significant pronounced tails.

histograms: for the dithered data $\chi^2 = 0.95$ and for the non-dithered data $\chi^2 = 1.18$. However, in the total spectrum the effect is marginal since the gaussian fits to the histograms completely overlap. The core width of the histogram is the same for both dithered and non-dithered data.

The outliers are caused by warm pixels, causing extra systematic 'noise', which is clealry reduced in the ditherd spectrum. For the bulk of the spectral bins, for the current average quality of the CCD's the impact of dithering for a 50 ks exposure on mkn421 on general noise is limited. However, some CCD's have more warm pixels then others. Fig 5 shows the histograms of fit residues for CCD's 5 and 6 (RGS1). Apart from a bit more pronounced tails of the histogram of the non-dithered data (more outliers), also the gaussian fit of the non-dithered data shows a larger width than the dithed case. Here, the dithering does improve the general spectrum statistics.

It seems the 50 ks Mkn421 observation is a boundary case. For this observaton given source statistics, some CCD's do benifit from dithering, others not yet. For longer integration times dithering is expected to improve general spectrum statistics.

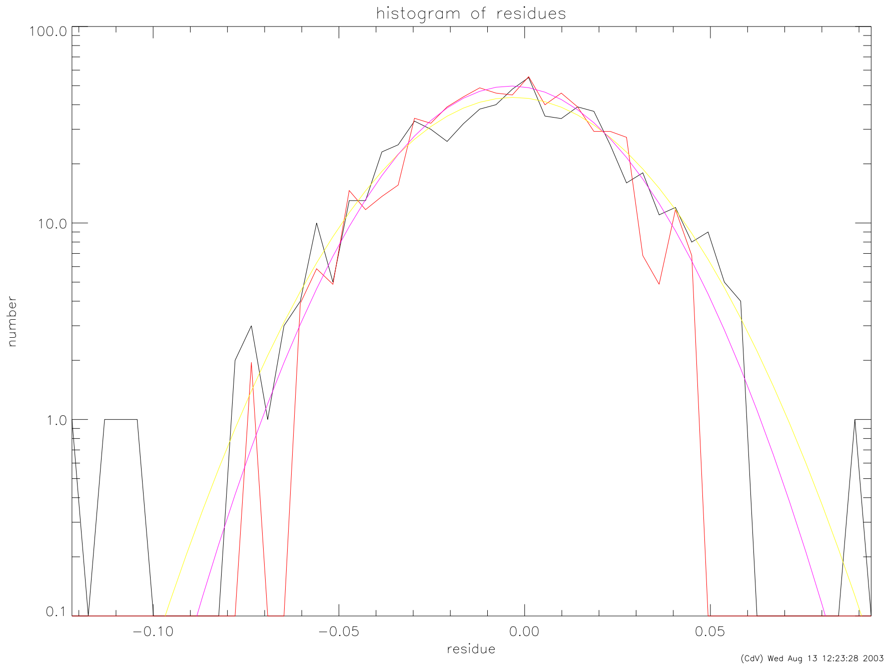

Figure 5: Histogram of fit residues on the smoothed spectrum of CCD's 5 and 6. Black line is the non-dither data while the red line is the dithered observation. The yellow and purple lines are gaussian fits to the respective data. In this case, due to the somewhat lower quality of the CCD's, the gaussian for the non-dithered case shows a larger spread, in addition to the more pronounced tails.

4 Conclusions

A comparison has been made between dithered and non-dithered spectra. The following conclusions can be reached:

- With proper setting of parameters the SAS can handle dithered observations.
- Dithering will remove gaps due to bad pixels and CCD boundaries. Any observation will benefit from this. Especially those observations where the main spectral features of interest are on CCD's which do not have operating counterparts on the other RGS.
- Possible single systematic features due to warm pixels can be significantly reduced by dithering. Any observation which concentrates on individual narrow line features will benefit from dithering.
- Outside local 'outliers' (which of course will always improve when dithering), statistics of the bulk of the spectral bins are expected improve to from dithering too, when observation times exceed 50 ks on bright sources.

- It is advisable to offer ‘dithering’ to users as a supported observational mode for those users which concentrate on isolated narrow features in spectral areas where there is no redundant CCD between RGS’s and/or plan very long integration times. This mode should then be properly decribed (with its purpose and features) in the users handbook.