Characterizing the S3 Low Energy Response with the SMC SNR 1E0102-72.3

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Calibration observations of the SMC supernova remnant 1E0102-72.3 indicate that problems exist with the response of the S3 chip at energies below about 1 keV, and especially at the oxygen lines below 0.7 keV.

To assess these problems we have created a model spectrum based on the grating observations of this target which allows detector gains for the four strong line complexes (O VII, O VIII, Ne IX, and Ne X) to vary independently. We find that the issue of determining gains at low energies is bound up with the possibility that the line widths at these energies in the released FEF files may be too large by a few percent.

We attempt to set limits on the absolute gains at the 4 line complexes, and the difference between the gains at the O VII complex (c. 568 eV) and the O VIII Lyman alpha line (653.61 eV).

The median gain error for all observations for both oxygen lines on nodes 0 and 1 of the S3 chip are 2.6%. At the neon lines we get 0.8%.

Observation Analysis I

The following observations of 1E0102-72.3 on S3 were analyzed:

OBSID	Date	Node	Chipx	Chipy
1308	12/2000	0	129:160	481:512
1530	06/2001	0	97:128	481:512
2843	12/2001	0	97:128	481:512
2850	06/2002	0	97:128	481:512
141	05/2000	1	353:384	257:288
1702	05/2000	1	353:384	737:768
1311	12/2000	1	353:384	481:512
1531	06/2001	1	353:384	481:512
2844	12/2001	1	385:416	481:512
2851	06/2002	1	353:384	481:512
3520	02/2003	1	353:384	481:512

Table 1: Observation date, and position information.

All Spectral files were created from reprocessed event 1 files using standard Ciao Threads. Filtering on chip, energy, grade, and GTI were all done. Flaring was not checked for due to the overall brightness of the SNR in relation to typical flaring.

The resulting files were fit using XSPEC. The following conditions were applied before fitting.

- The ARF was removed. While this would not allow sensible results for line normalizations, it would remove any problems which might occur due to QE variations at different energies.
- The energy range over which fitting was performed was 0.3 keV to 5.0 keV. The energy range which was given to the CIAO command mkrmf generation was 0.1 keV to 11.0 keV in bins of 5 eV width.

Details about the model described in table 2:

- Using a modified version of the model created by P. Plucinsky (Plucinsky, et al. 2001).
- Use information from HETG and RGS to identify strongest lines in the spectrum. Line intensity ratios in the model are from Flanagan, K. and Fredricks, A. (private communication).
- XSPEC representation of the model is: 4 Gaussians + phabs + vphabs + Bremsstrahlung + 24 Gaussians
- The first four Gaussians correspond to four gain values. The energy of the Gaussians are used as the gain parameter, while the line width was used as a multiplicative factor for line widths.
- Two component absorption, one component for the galactic absorption with solar abundances and one component for the SMC with reduced abundances (Russell and Dopita 1992) which are set to 2×10^{20} and 5.36×10^{20} respectively in order to reduce the number of free parameters
- Line energies, descriptions, and peak emissivities are taken from Astrophysical Plasma Emission Database of Smith et al. (see “hea-www.harvard.edu/APEC/”).

Included Model Lines

Table 2: Included Lines

Energy (keV)	Line Description	Gratings Relations (ratios)	Gain/Width Relations (multiplicative parameter)
0.561	O7 $1s^2(^1S_0) - 1s2s(^3S_1)$[For]	free	1
0.574	O7 $1s^2(^1S_0) - 1s2p(^1P_1)$[Res]	1.757 × O7[For]	1
0.654	O8 $1s(^2S_{1/2}) - 2p(^2P_{n/2})$ [Ly α]	free	2
0.665	O7 $1s^2(^1S_0) - 1s3p(^1P_1)$	0.4595 × O7[For]	2
0.698	O7 $1s^2(^1S_0) - 1s4p(^1P_1)$	0.1530 × O8[Lyα]	2
0.774	O8 $1s(^2S_{1/2}) - 3p(^2P_{n/2})$ [Ly β]	free	2
0.817	O8 $1s\ (^2S_{1/2}) - 4p\ (^2P_{n/2})$ [Ly γ]	0.100 × O8[Lyα]	2
0.837	O8 $1s\ (^2S_{1/2}) - 5p\ (^2P_{n/2})$ [Ly δ]	free	2
0.905	Ne9 $1s^2(^1S_0) - 1s2s(^3S_1)$[For]	free	3
0.923	Ne9 $1s^2(^1S_0) - 1s2p(^1P_1)$[Res]	1.923 × Ne9[For]	3
1.022	Ne10 $1s\ (^2S_{1/2}) - 2p\ (^2P_{n/2})$ [Ly α]	free	4
1.073	Ne9 $1s^2\ (^1S_0) - 1s3p\ (^1P_1)$	0.4423 × Ne9[For]	4
1.127	Ne9 $1s^2\ (^1S_0) - 1s4p\ (^1P_1)$	free	4
1.150	Ne9 $1s^2(^1S_0) - 1s5p\ (^1P_1)$	free	4
1.212	Ne10 $1s\ (^2S_{1/2}) - 3p\ (^2P_{n/2})$ [Ly β]	0.216 × Ne10[Ly α]	none
1.277	Ne10 $1s\ (^2S_{1/2}) - 4p\ (^2P_{n/2})$ [Ly γ]	free	none
1.331	Mg11 $1s^2\ (^1S_0) - 1s2s\ (^3S_1)$ [For]	free	none
1.352	Mg11 $1s^2\ (^1S_0) - 1s2p\ (^1P_1)$ [Res]	free	none
1.473	Mg12 $1s\ ^2S_{1/2} - 2p\ ^2P_{n/2}$ [Ly α]	0.380 × Mg11[Res]	none
1.579	Mg11 $1s^2\ (^1S_0) - 1s3p\ (^1P_1)$	free	none
1.696	Mg11 $1s^2\ (^1S_0) - 1s5p\ (^1P_1)$	free	none
1.840	Si13 $1s^2\ (^1S_0) - 1s2s\ (^3S_1)$ [For]	free	none
2.006	Si14 $1s\ ^2S_{1/2} - 2p\ (^2P_{n/2})$ [Ly α]	free	none
2.375	Si14 $1s\ ^2S_{1/2} - 3p\ (^2P_{n/2})$ [Ly β]	free	none

Results

Table 3: Four Gain Results for Node 0 & 1

Obsid	Date	Node	Gain 1 OVII	Gain 2 OVIII	Gain 3 NeIX	Gain 4 NeIX	reduced-Chi
1308	12/2000	0	1.043	1.026	1.017	1.008	0.719
1530	06/2001	0	1.044	1.026	1.014	1.008	0.866
2843	12/2001	0	1.035	1.020	1.014	1.006	0.793
2850	06/2002	0	1.044	1.026	1.013	1.005	0.882
141	05/2000	1	1.029	0.9887	1.008	1.005	0.968
1702	05/2000	1	1.028	1.002	1.009	1.005	0.769
1311	12/2000	1	1.028	0.9953	1.009	1.005	0.847
1531	06/2001	1	1.028	1.009	1.012	1.009	0.835
2844	12/2001	1	1.029	0.9950	1.011	1.005	0.752
2851	06/2002	1	1.038	0.9873	1.012	1.005	0.916
3520	02/2003	1	1.030	0.9919	1.009	1.005	0.898

- Table 3 is the gain results of fits to the 1E0102-72.3 spectra with a four gain model. The results show surprising consistency across nearly 3 years of observation times.

Selected 4 Gain Model Fits

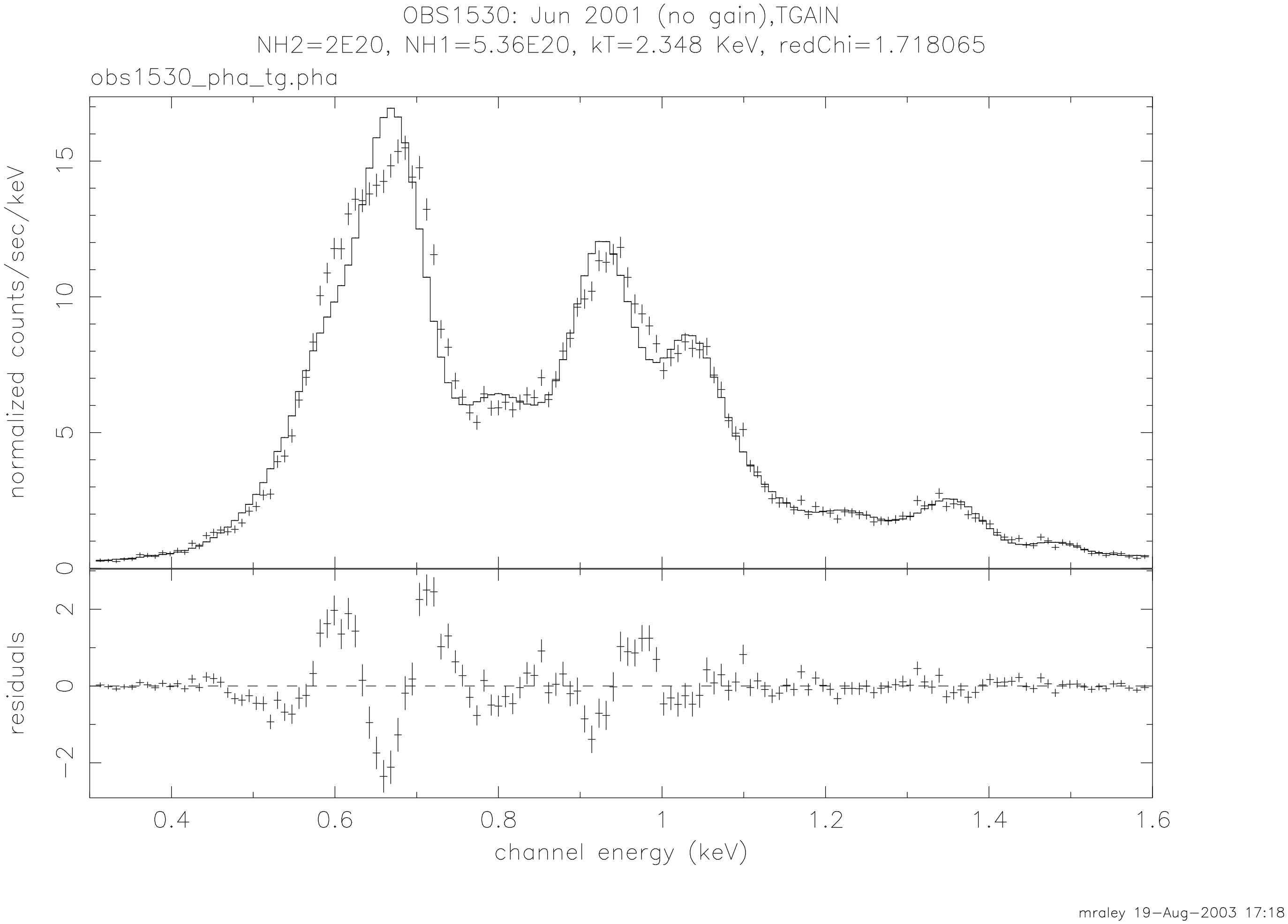


Figure 1: Fit to Obsid 1530 with no gain adjustment

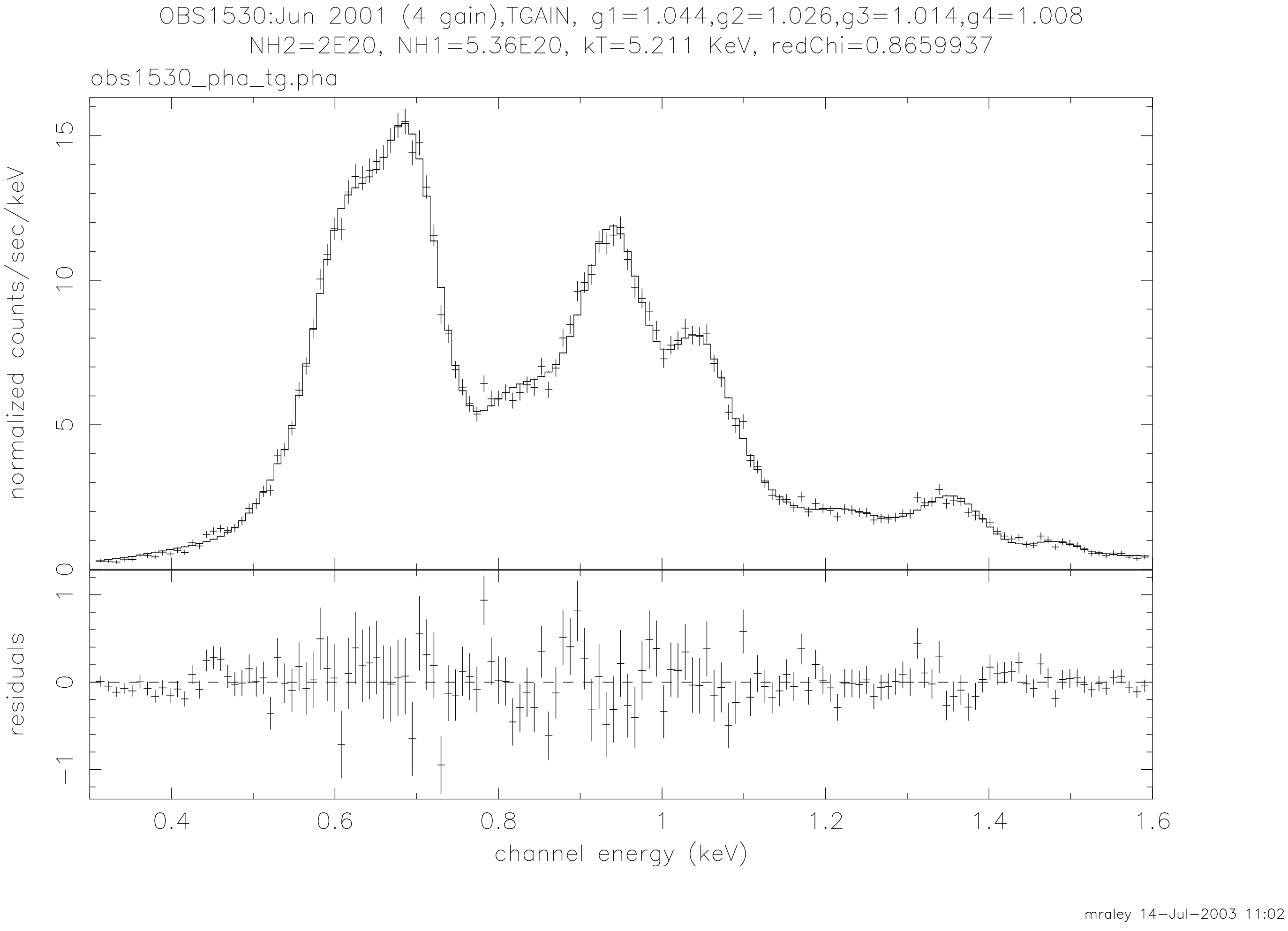


Figure 2: Fit to Obsid 1530 with 4 gain adjustmentent

Selected 4 Gain Model Fits

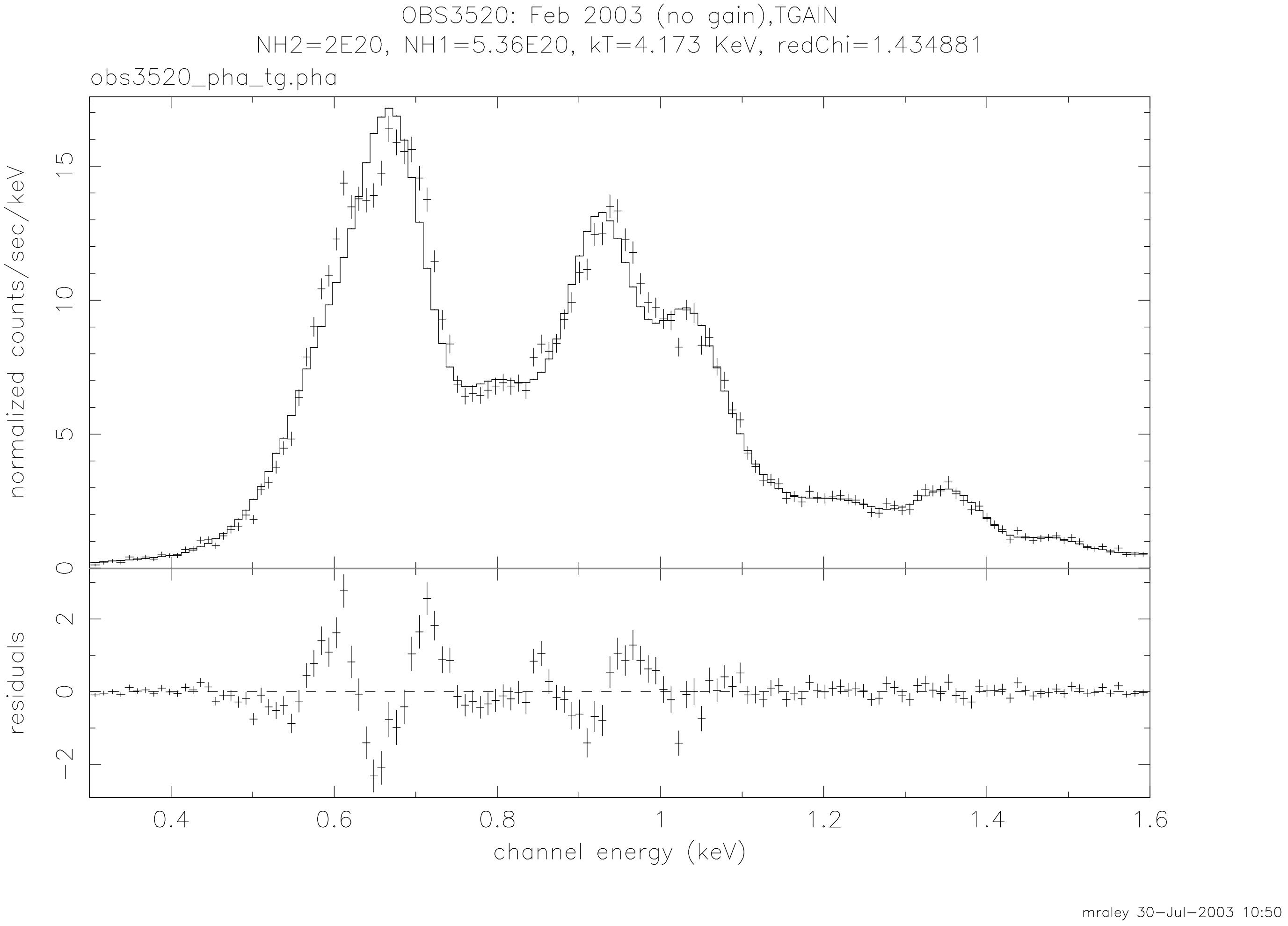


Figure 3: Fit to Obsid 3520 with no gain adjustment

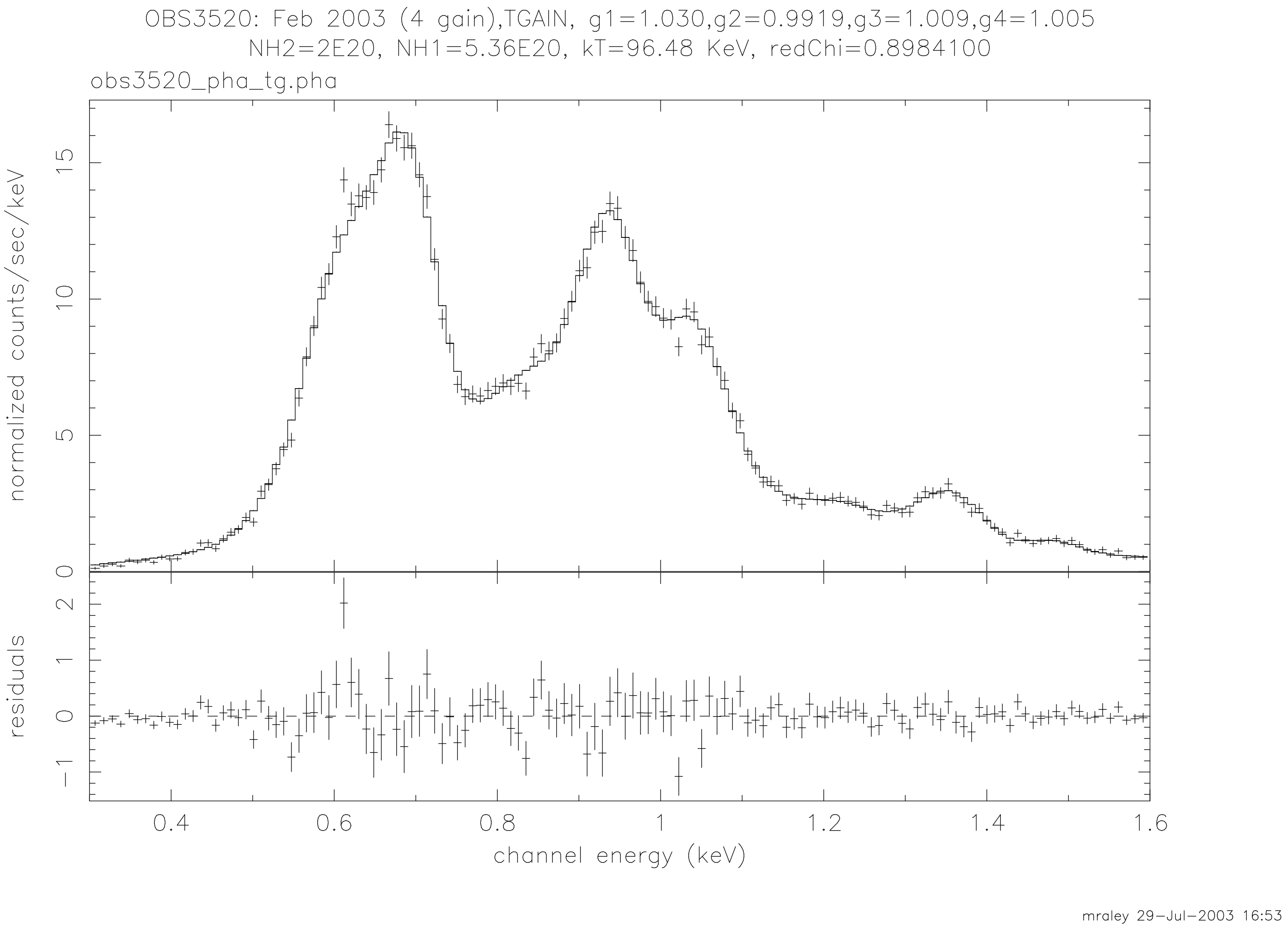


Figure 4: Fit to Obsid 3520 with 4 gain adjustmentent

Response Width Analysis

It has been suspected for some time that the line widths in the released S3 ACIS response matrices were too large. If true, this could correlate any gain errors measured. We reduced the sizes of the main line peaks in th released matrices by 30%, and allowed the widths to vary in the same manner as the gains (Table 2). The following process was applied to the resulting fits:

- Take best fit for a subset of observations (Table 1), and allow the gains to vary.
- Given best fit, freeze OVIII gain, and set the width for OVIII to that of OVII.
- Find confidence contours with Xspec.

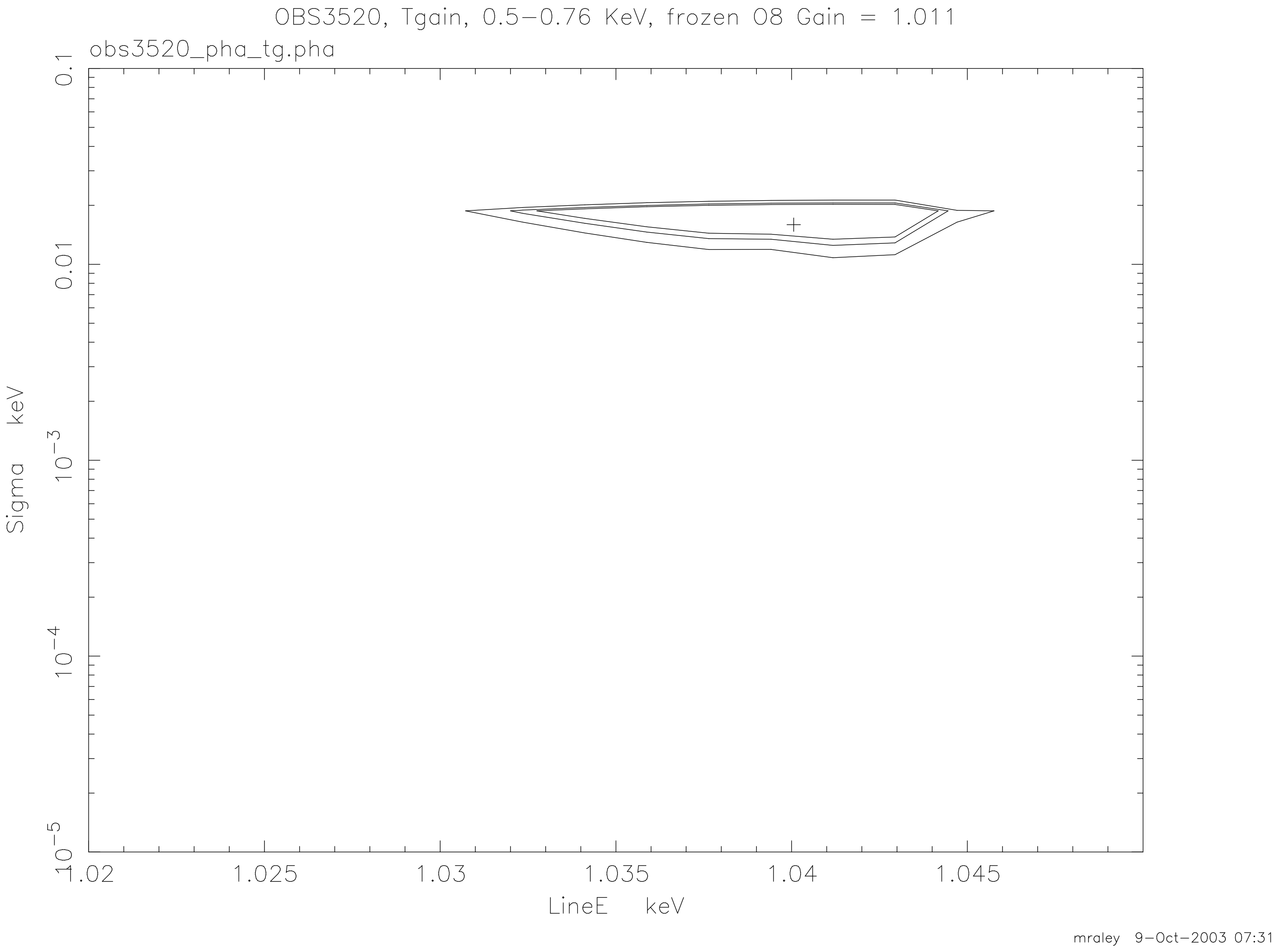
The results of the test showed that the line widths are independent of the gain.

When the best fit width results are combined with the narrowed response matrices, we arrive at the following results:

Table 4: Width Results for Selected Observations

Obsid	Date	Node	Released Width ADU	Fit Width σ (keV)	Adjusted Width ADU
1530	06/2001	0	19.2971	2.4232E-2	15.2714
1311	12/2000	1	19.2971	1.6144E-2	15.0723
3520	02/2003	1	19.2971	1.6144E-2	15.0723

Selected OVII Gain and Width Contour



OVII & OVIII Gain Contours

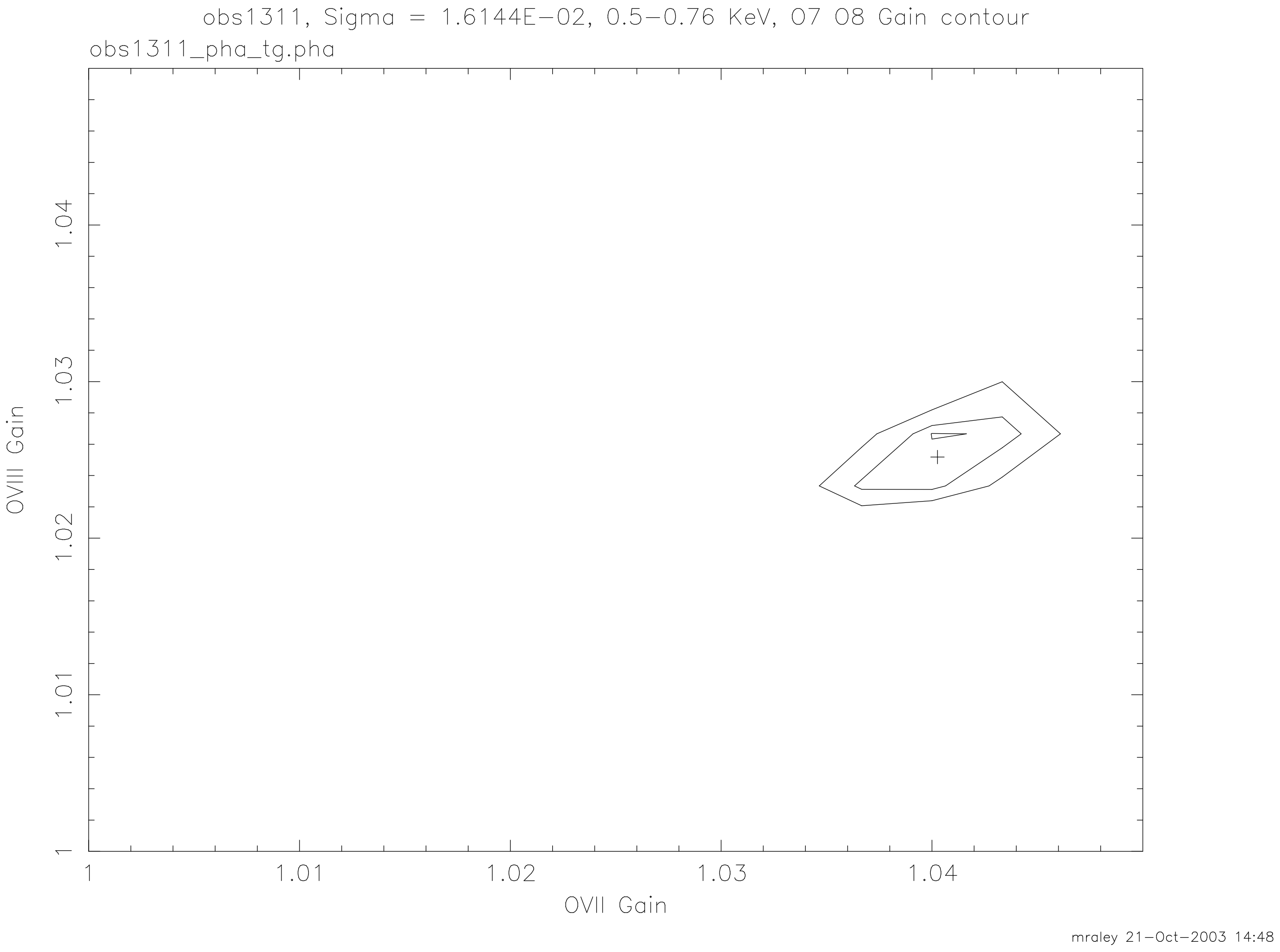


Figure 5: Gain contour of Obsid 1311 with small width response matrices

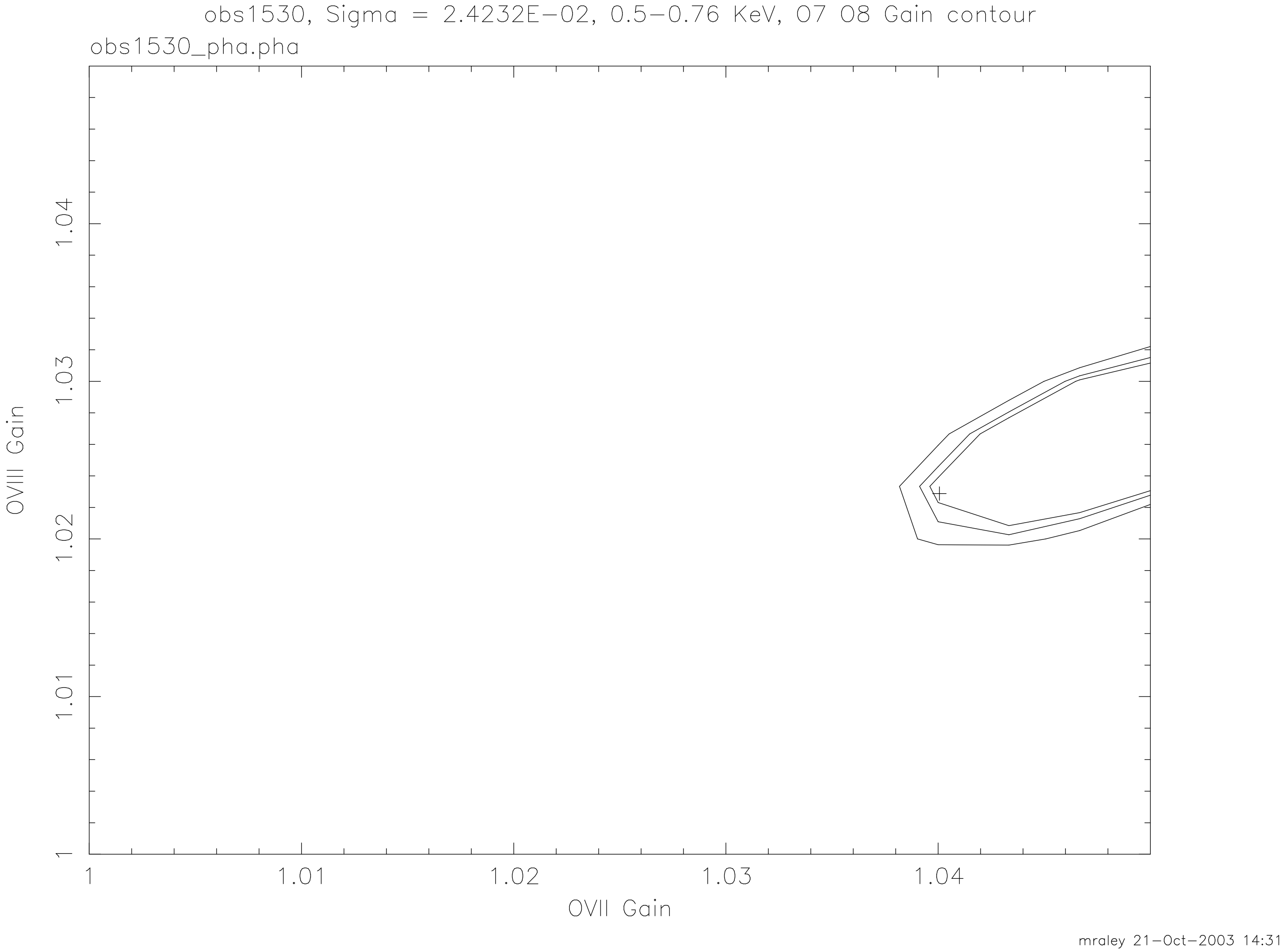


Figure 6: Gain contour of Obsid 1530 with small width response matrices

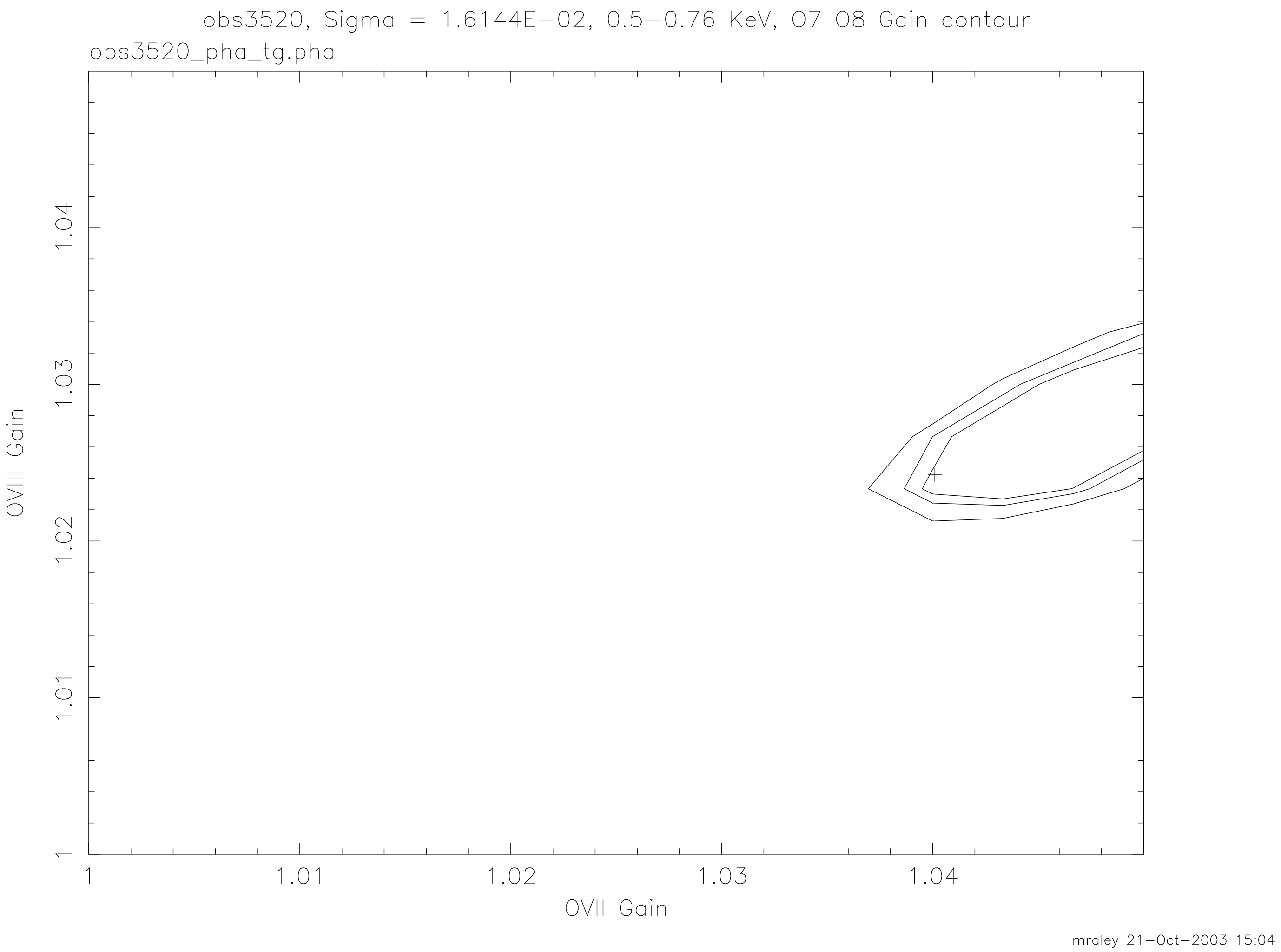


Figure 7: Gain contour of Obsid 3520 with small width response matrices

Conclusions

- This method shows that there does exist an overestimation of line widths in the released ACIS S3 Response Matrices, and that they are correctable.
- We have shown that the line width discrepancies are independent of the gain errors.
- Once the width issue has been eliminated, the gain errors do not appear to be position or time dependent when TGAIN is used.
- We suggest that the next release of ACIS S3 responses have narrower widths, and that the gains at OVII and OVIII should see $\sim 4\%$ and 2% gain shifts respectively.

Future Work

The results presented here provide optimism that the errors associated with low energy response are quantifiable and correctable using observations we already have in the archive. The spatial independence within node 1 & similarity to node 0 provide a suggested course of action.

- First, additional observations of 1E0102-72.3 (Table 1) should be analyzed using this method to determine if there is any spatial dependence of line widths.
- Secondly, additional analysis should be performed to verify the line widths for the Ne complex in 1E0102-72.3
- Lastly, further pointings of 1E0102-72.3 should be taken on ACIS S3 on nodes 2 & 3. Given the assumption of time and spatial independence within the nodes, a few pointings on these nodes should be more than enough to calibrate the low energy gain variations.