July 30, 2004

Corrections for time-dependence of ACIS gain

A. Vikhlinin, R. Edgar, N. Schulz

Abstract

There is a secular drift of the average PHA values for photons of a fixed energy E. This drift is caused primarily by gradual changes of the CTI in ACIS CCDs and also due to electronic drift in I2. These percent-level changes in the gain are very important for the scientific analysis. However, the gain changes are sufficiently small so that possible modifications of the *shape* of the ACIS spectral response can be neglected. This opens a possibility for a simple but sufficiently accurate correction: a pre-computed time- and energy-dependent shift can be added to the PHA values and the existing gain table is applied to the modified PHA's to recompute the photon energies and PI channels. Existing RMF calibration can be used with the corrected data.

1 Time dependence of ACIS CTI and gain

ACIS spectral response slowly evolves both because of changes in the CTI and evolution of the electronic gain in some of the CCDs. All relevant information can be found in C. Grant's presentation at 2002's *Chandra* calibration workshop: `http://space.mit.edu/~cgrant/acis.html`

2 Calibration data and time periods

Two different datasets are available for calibration of the time dependence of ACIS gain:

- *External cal source* (ECS). These measurements are taken regularly and cover the entire ACIS detector. They allow to study the time-dependence of ACIS gain with a 1 month resolution and its positional dependence in regions as small as 32×32 pixels. Unfortunately, the low energy part of the ACIS response is not adequately sampled by ECS because there are no bright emission lines below 1.49 keV.
- *E0102-72.* This SNR has a line-dominated spectrum with bright O and Ne emission lines whose energies are known from the HETG observation. We observe E0102-72 twice a year to monitor the evolution of the low-energy ($0.55 < E < 1.1$ keV) ACIS gain. Unfortunately, E0102-72 is observed only in a small number of locations and it is almost impossible to deduce the position-dependence of ACIS gain from these data.

Our approach is to derive the gain corrections from the ECS data and to verify their extrapolation to low energies by E0102-72 data. We use the ECS data integrated in a number of short observations spanning 3 months long periods starting in February 2000. This time resolution is adequate to sample the slow gain evolution (§ 3.4).

3 Calibration procedure

The released ACIS gain and RMF calibration was adjusted to the data taken in early 2000 (February–April), just after the ACIS focal plane temperature was lowered to -120 C. Using these calibration products, we derive the fractional change relative to these epoch by fitting the calibration data taken at later times.

The emission lines in the ECS spectrum are well-separated and their locations can be derived directly, without any spectral fitting. the main emission lines in the ECS spectrum. The ratio of the best-fit energies and the nominal energies gives the fractional gain change, $\Delta E/E$, for the given epoch as a function of position.

The E0102-72 spectra are fitted with a physically motivated model consisting of an absorbed bremsstrahlung continuum and a number of emission lines whose energies and flux ratios are fixed based on the HETG observation. The model also includes two multiplicative factors to the line energies for O and Ne emission complexes. The best-fit values of these factors represent the gain change at $E \simeq 0.6$ keV (O) and $\simeq 1.0$ keV (Ne).

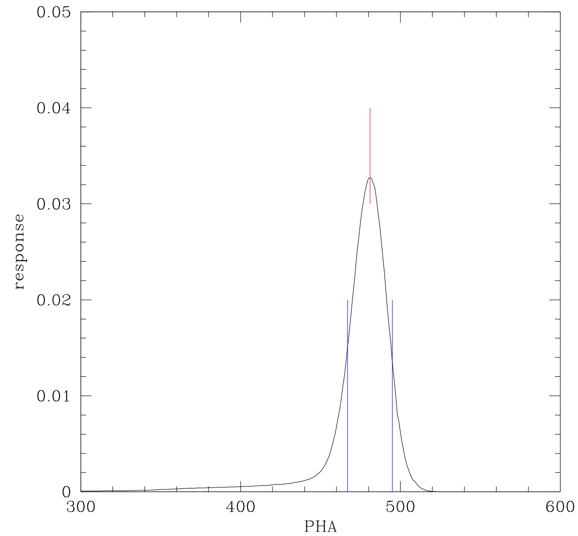

Fig. 1— Illustration of the peak measurement procedure for the gain calibration. Red line shows the measured PHA location, and the blue line show the FWHM window used in the iterative procedure (eq. 1).

3.1 Line locations in the ECS spectra

The line locations in the well-exposed ECS spectra are measured using the following procedure. First, the main peaks are identified. Second, we determine FWHM of each peak (the window where the response is > 0.5 of the peak value). Finally, we find iteratively the average PHA channel within the FWHM window:

$$C = \mathrm{nint}\,(P^{(k)}); \quad P^{(k+1)} = \sum_{i=C-W/2}^{C+W/2} i\,S_i \times \left(\sum_{i=C-W/2}^{C+W/2} S_i\right)^{-1}, \tag{1}$$

where $P^{(k)}$ is the average value on the k-th iteration, W is the FWHM, and S_i is the observed spectrum in the i-th PHA channel. Effectively, this procedure finds the peak location (but with greater than a 1-channel accuracy) as illustrated in Fig. 1.

3.2 `CHIPY`-dependence of the ECS gain change

Comparison of the line locations measured for February–April, 2000 and the epoch of interest gives the gain drift at 3 calibration energies. Figure 2 shows an example of `CHIPY`-dependence of the fractional gain change at $E = 1.49$, 4.51, and 5.89 keV. To smooth out statistical uncertainties, we use the 4-th order polynomial fits shown by solid lines. Note that the fractional gain change increases at large distances from the readout and towards low energies.

3.3 Energy dependence of the gain change

If there are no changes in the internal gain of the amplifiers, the line shift ΔPHA represents the increase in the charge loss due to CTI. The phenomenological model of the CTI developed by the ACIS IPI team predicts that the energy dependence at each location is approximately $\Delta\mathrm{PHA} = AE^{1/2}$. A similar energy dependence is indeed observed for the time-varying component of ACIS gain in most CCDs (Fig. 3).

At least one CCD (I2) shows strong variations in the internal electronic gain on top of the increase in the CTI. Such changes can be represented by a linear function of energy, $\Delta\mathrm{PHA} = BE + C$. Therefore, the general function which describes the dependence of gain correction on energy is

$$\Delta\mathrm{PHA} = AE^{1/2} + BE + C \tag{2}$$

This is an over-determined model because we have to fit three coefficients to three data points. At present, we fix $C = 0$ and $B = 0$ in all CCDs except for I2. In I2, the internal gain evolution seems to be described by the BE term and so we fix $C = 0$ and fit B in this CCD.

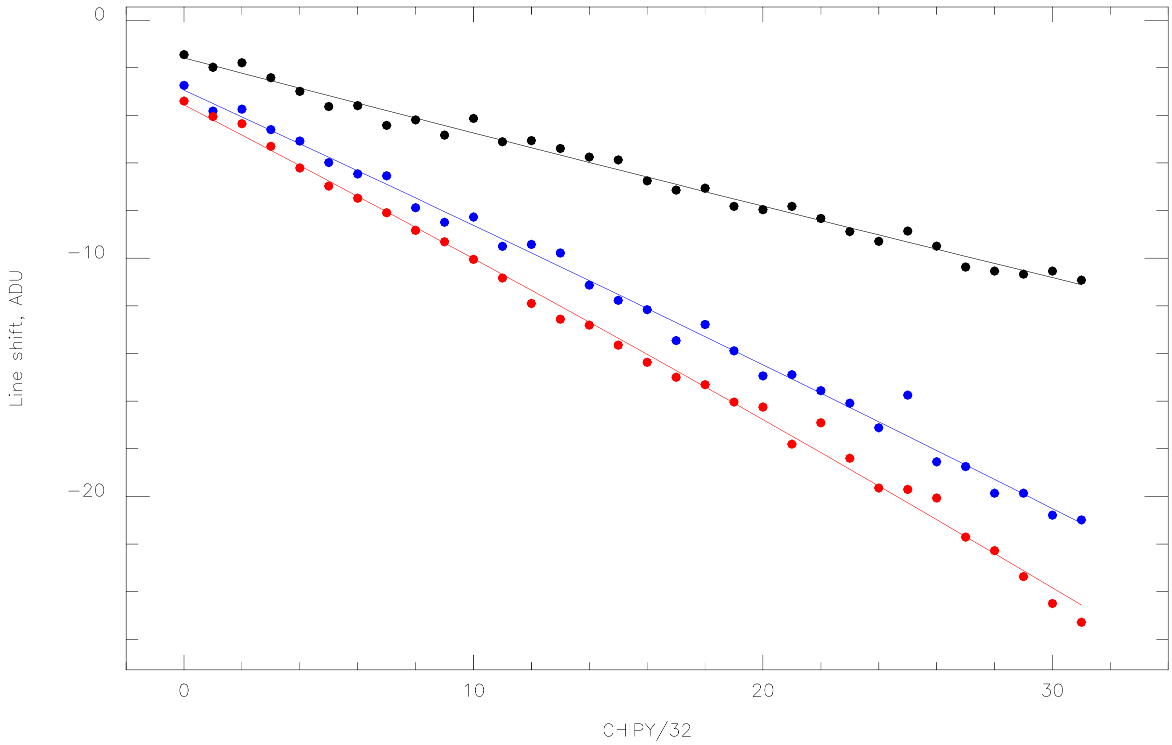

Fig. 2— Centroid location shift as a function of CHIPY for ECS lines of Al (E = 1.49 keV, black), Ti (E = 4.51 keV, blue), and Mn (E = 5.89 keV, red). Solid lines show the 4-th order polynomial fits. The data are for node 2 of the I3 CCD. The *rms* scatter arround the polynomial fits is 0.08% for the Al Ka line and below 0.03% for the Ti and Mn lines.

Equation (2) is fit to the data at 32 CHIPY steps for each node of the FI CCDs and for ΔCHIPX = 32 steps in S3. Whenever B or C coefficients are needed, they are likely to be independent of CHIPY. Therefore, we average their best-fit values over the CHIPY steps and then refit the A coefficients with B or C held fixed.

The best-fit relation (2) is used to precompute the correction lookup tables, ΔPHA(PHA), for each location and epoch. A simple C program uses these tables to apply correction to the PHA values in either level1 or level2 event files.

3.4 Time dependence of the gain change

After Spring 2000, ACIS gain changes in most CCDs are slow (Fig. 4). Even at early times, the gain changes between the neighboring 3-month intervals are acceptably small ($\sim$ 0.3% or less).

4 Validation

4.1 (No) changes in the shape of the spectral response

External cal. source data do not show any detectable changes in the shape of the ACIS response except for the PHA shifts described above (e.g., Fig. 5 and 6).

4.2 Gain

Validity of the gain correction has been verified by fitting the ECS spectra (this is mostly a sanity check) and using E0102-72 to verify the correction at low energies.

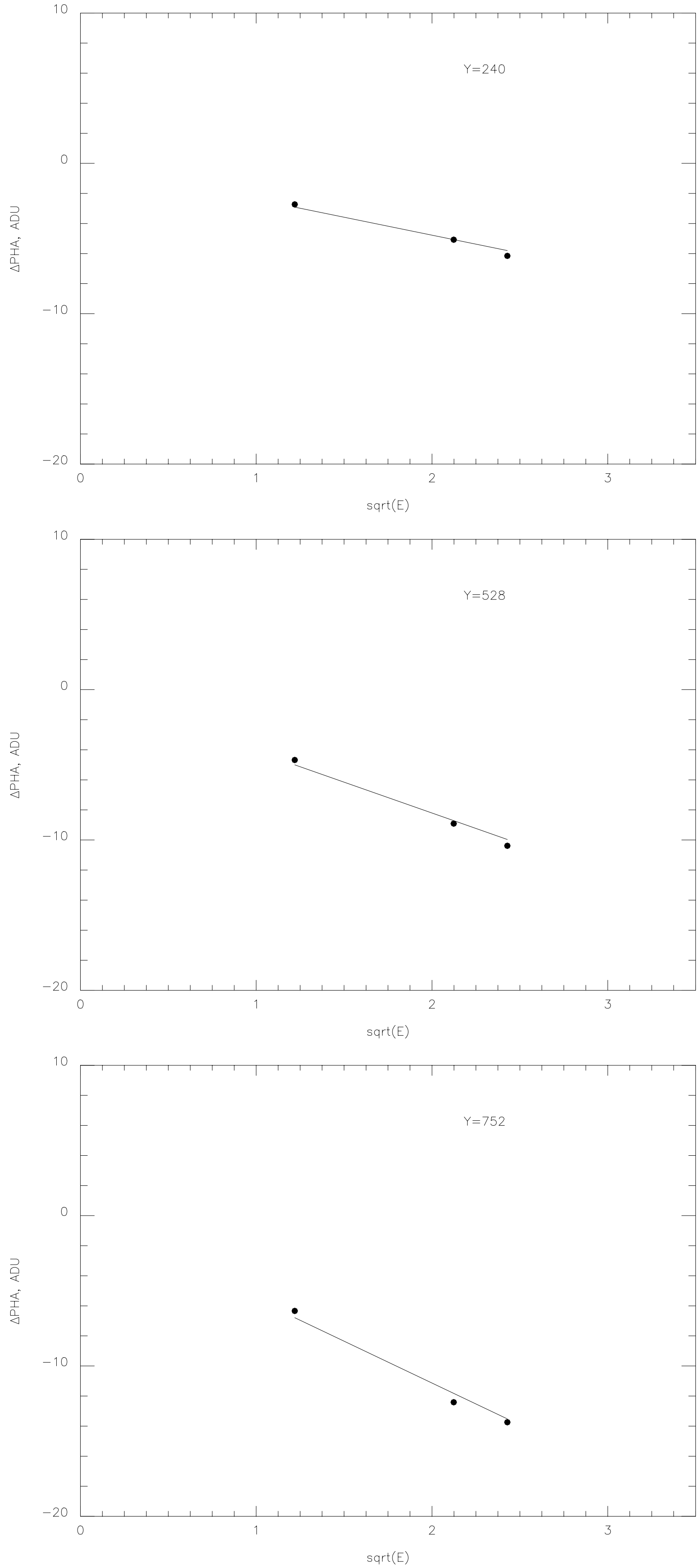

Fig. 3— PHA shift as a function of energy for 3 locations in node 2 of I3. Lines show the best fit $\Delta\mathrm{PHA} \propto E^{1/2}$ relations.

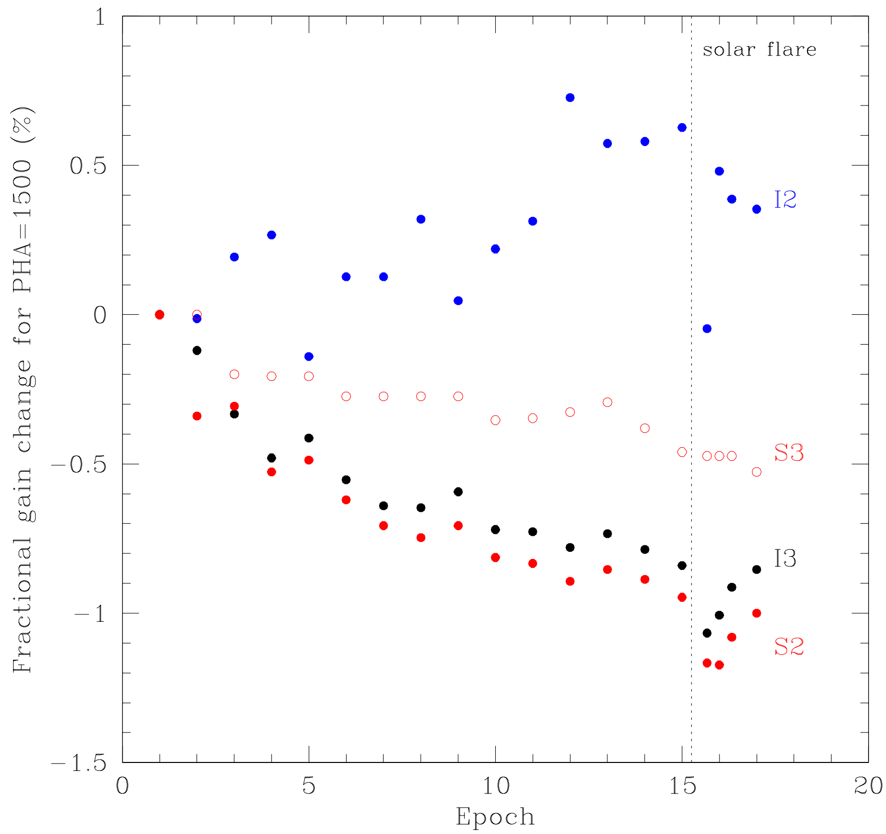

Fig. 4— History of the gain changes in the center of the I2, I3, S2, and S3 chips for the average PHA = 1500. Each epoch spans 3 months starting February, 2000. Note the positive drift in I2 which is caused by the evolution of the electronic gain.

The ECS fits produce excellent results and demonstrate that the original gain calibration is restored to better than 0.2% at high energies. The summary of the low-energy results from E0102-72 is given below. Essentially, the line energies for both O ($E \approx 0.6$ keV) and Ne ($E \approx 0.9$ keV) came out within 1% or better of their nominal values (Table 1).

5 Software

With the CIAO release 3.1 time-dependent gain correction is implemented within `acis_process_events` and all necessary calibration data are included in the CALDB. Please refer to the analysis thread `http://cxc.harvard.edu/ciao/threads/acistimegain`.

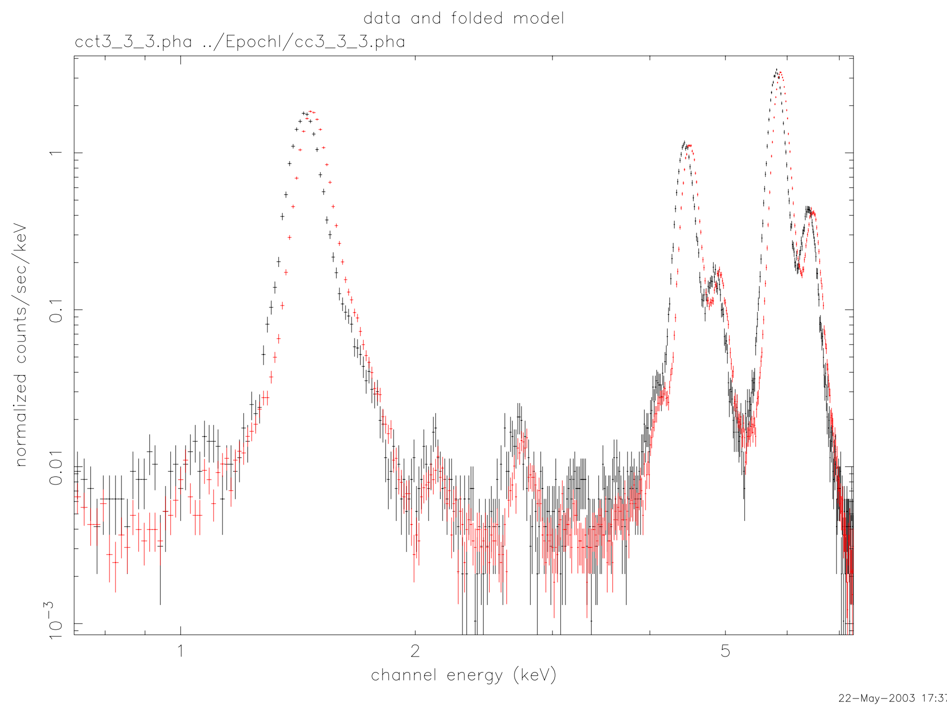

Fig. 5— Comparison of the ECS spectra in the aim point quadrant of I3 observed in Feb–Apr of 2000 (red) and Nov2002-Jan2003 (black). No correction has been applied.

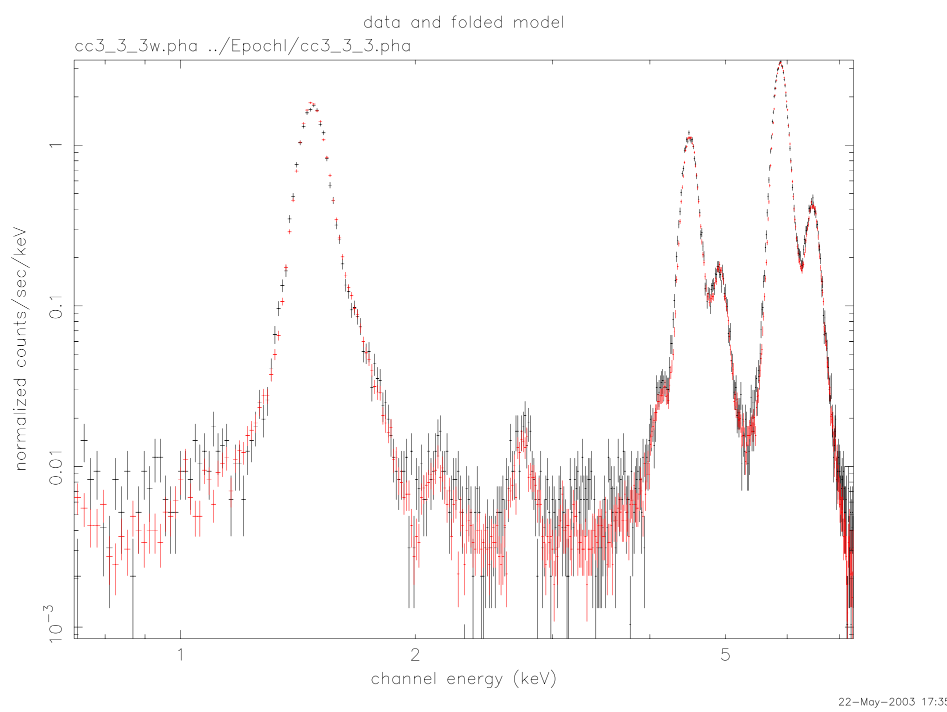

Fig. 6— Same as Fig. 5 but with the PHA correction applied. Note an excellent agreement, both in terms of the peak locations and their shape.

Table 1— Gain result from E0102-72 observations

O_gain and Ne_gain in the following table are defined as the ratio of the measured and nominal energies for the O and Ne complexes.

CCD	OBSID	Epoch	chipx	chipy	O_gain	Ne_gain
I0	1542	VI	257:512	513:544	1.0075	0.9970
I0	2840	VIII	257:512	513:544	1.0075	0.9970
I1	444	I	1:256	97:128	1.0073	1.0040
I1	445	I	1:256	481:512	1.0320	1.0240
I1	1543	VI	257:512	481:512	1.0072	1.0060
I1	2841	VIII	257:512	449:480	1.0073	1.0060
I2	1544	VI	257:512	513:544	0.9990	0.9970
I2	2842	VIII	257:512	513:544	1.0074	0.9970
I3	1537	VI	1:256	481:512	0.9987	1.0025
I3	2839	VIII	1:256	449:480	0.9988	0.9970
I3	1536	VI	257:512	481:512	1.0073	0.9970
I3	2838	VIII	257:512	449:480	1.0072	0.9970
I3	420	I	513:768	97:128	1.0083	1.0100
I3	140	I	513:768	289:320	1.0073	0.9970
I3	136	I	513:768	449:480	1.0128	1.0140
I3	1535	VI	513:768	481:512	1.0075	0.9970
I3	2837	VIII	513:768	449:480	1.0074	0.9970
I3	439	I	513:768	673:704	1.0085	1.0085
I3	440	I	513:768	897:928	1.0048	0.9970
I3	1533	VI	769:1024	97:128	1.0072	1.0060
I3	2835	VIII	769:1024	97:128	1.0074	1.0060
I3	1534	VI	769:1024	481:512	1.0075	0.9970
I3	2836	VIII	769:1024	449:480	0.9988	0.9970
S2	1539	VI	513:768	481:512	0.9988	0.9970
S2	2847	VIII	513:768	481:512	0.9987	0.9970