Computation of the Times of Arrival for Continuous-Clocking Mode Events

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⋮

The Problem

The TIMEs in continuous-clocking mode event files are the readout times, not the times of arrival.

- Analyses of the absolute TIMEs (or phases) suffer from an absolute offset of about 4.4 s.
- Searches for periodic signals suffer from periodic motion of the telescope (0.09 s peak-to-peak dither) and motion of the SIM relative to the telescope.

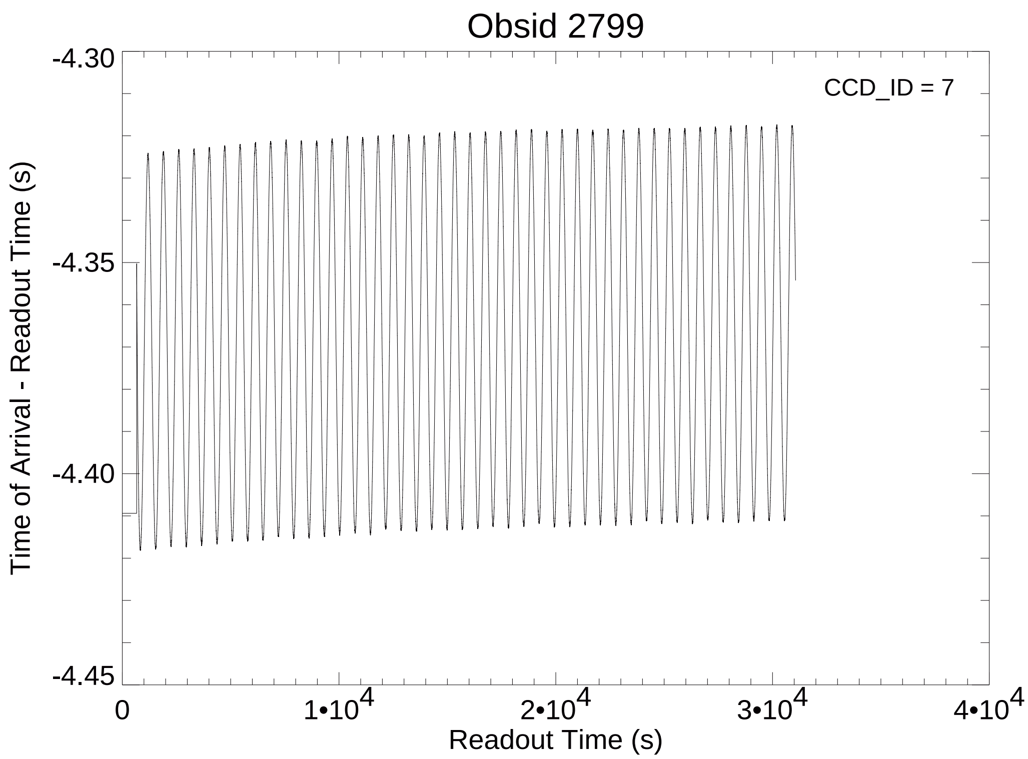

Fig. 1. The differences between the times of arrival and the readout times. The differences include the dither motion of the telescope (the periodic variations with an amplitude of 0.09 s), the motion of the SIM relative to the telescope (the 0.01 s gradual change in the dither envelope), and the 4.4 s of time it takes to move the charge through about 1540 pixels.

The Solution

The times of arrival are computed using the values of the quantities RA_TARG and DEC_TARG and the measured motion of the telescope and the SIM:

$$t_0 = t_1 - \mathrm{TIMEDEL} \times (\mathrm{CHIPY\_TARG} + 1028)\,, \tag{1}$$

where

t_0 = time of arrival,
t_1 = readout time,
TIMEDEL = row-to-row transfer time (e.g. 2.85 ms), and
CHIPY_TARG = CHIPY position of the source on the detector.

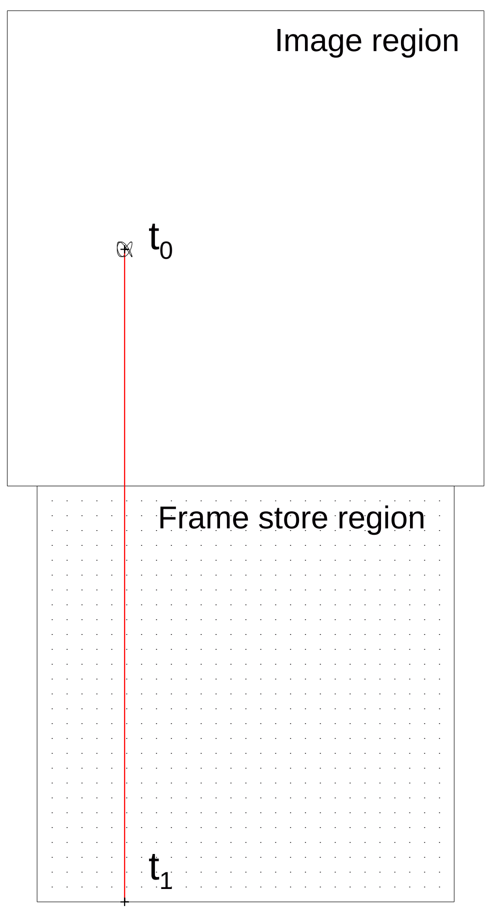

Fig. 2. A schematic of the difference between the time of arrival (t_0) and the readout time (t_1).

Usage

The algorithm shown in equation 1 is implemented in the tool acis_process_events. For example, the computation of the times of arrival can be applied by executing the command

```
acis_process_events
    infile=acisf02799_001N001_evt1.fits \
    outfile=acisf02799_100N001_evt1.fits \
    acaofffile=pcadf126659050N001_asol1.fits \
    eventdef="{d:time,d:time_ro,s:ccd_id,s:node_id,i:expno,s:chip,s:tdet,
    f:det,f:sky,s:phas,l:pha,f:energy,l:pi,s:fltgrade,s:grade,x:status}" \
    calc_cc_times=yes
```

The output includes the columns

TIME
TIME_RO

where TIME is the time of arrival and TIME_RO is the readout time.

The output also includes the header keyword

HDUCLAS3=CC_CORRECTED

It may be necessary to adjust the values of RA_TARG and DEC_TARG in either the header of the events file or in the observation parameter file before execution.

The algorithm will be available as part of the CIAO 2.3 release, which is scheduled for this month. We intend to implement this computation as part of the normal pipeline processing when we are confident the code is working well.

Accuracy & Precision

Refer to Arnold Rots's presentation at this workshop for a discusssion about tests of the accuracy of the times using observations of the Rapid Burster and the Crab pulsar.

The uncertainty of the computation of the times of arrival is limited by the

Component	Uncertainty
PSF	$\approx 1.1 \times$ TIMEDEL
Aspect reconstruction	$\approx 0.6 \times$ TIMEDEL (systematic)
	$\approx 0.2 \times$ TIMEDEL (statistical)
Implementation of equation 1	$\lesssim 0.04 \times$ TIMEDEL (systematic)
	$\lesssim 0.02 \times$ TIMEDEL (statistical)
TIMEDEL	$\lesssim 0.02 \times$ TIMEDEL
Total	$\approx 1.3 \times$ TIMEDEL

For a source on axis, the radius inside which 68% of the events occur is about $0\farcs55$. This corresponds to an uncertainty of about 1.1 pixels (i.e. $1.1 \times$ TIMEDEL).

Sixty-eight percent of the observations have absolute pointing errors of $0\farcs3$ (i.e. $0.6 \times$ TIMEDEL) or less. The dither can be removed to $0\farcs1$ (i.e. $0.2 \times$ TIMEDEL) or better.

As shown in the figures 3–5, the implementation of equation 1 has an absolute accuracy of about 0.04 pixels or better and the relative uncertainty is better than 0.02 pixels.

Collectively, the 1 σ uncertainty in the computation of the times of arrival is about 3.6 ms (i.e. $1.3 \times$ TIMEDEL) if the individual contributions are independent.

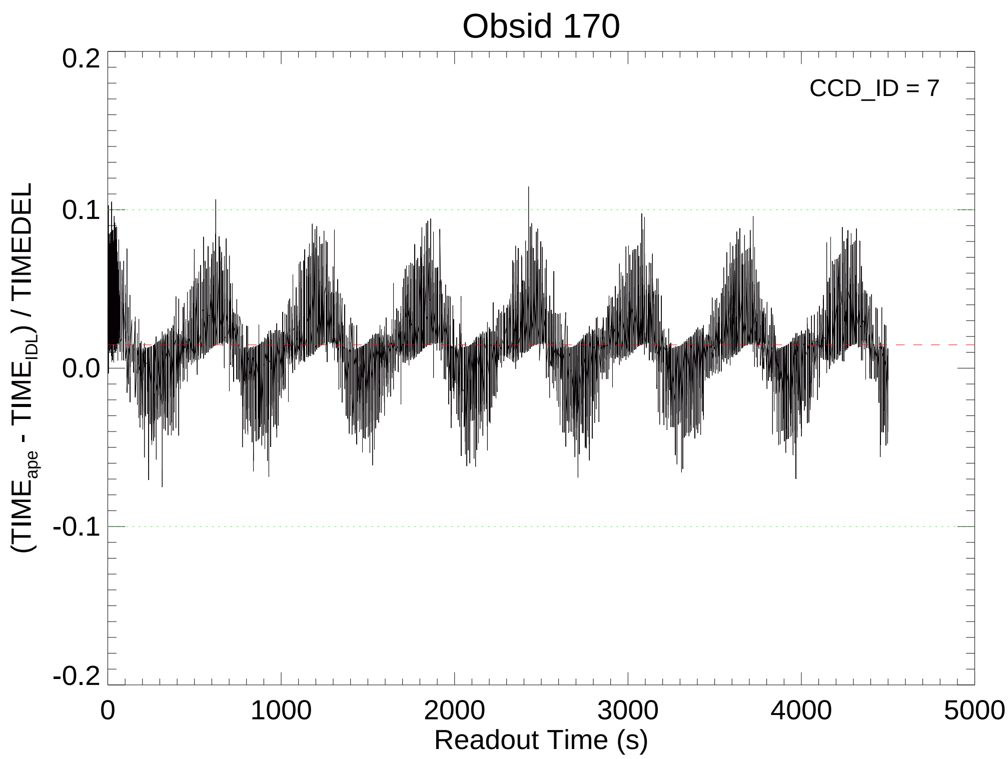

Fig. 3. The differences between the times of arrival computed using acis_process_events and the times computed using some IDL procedures.

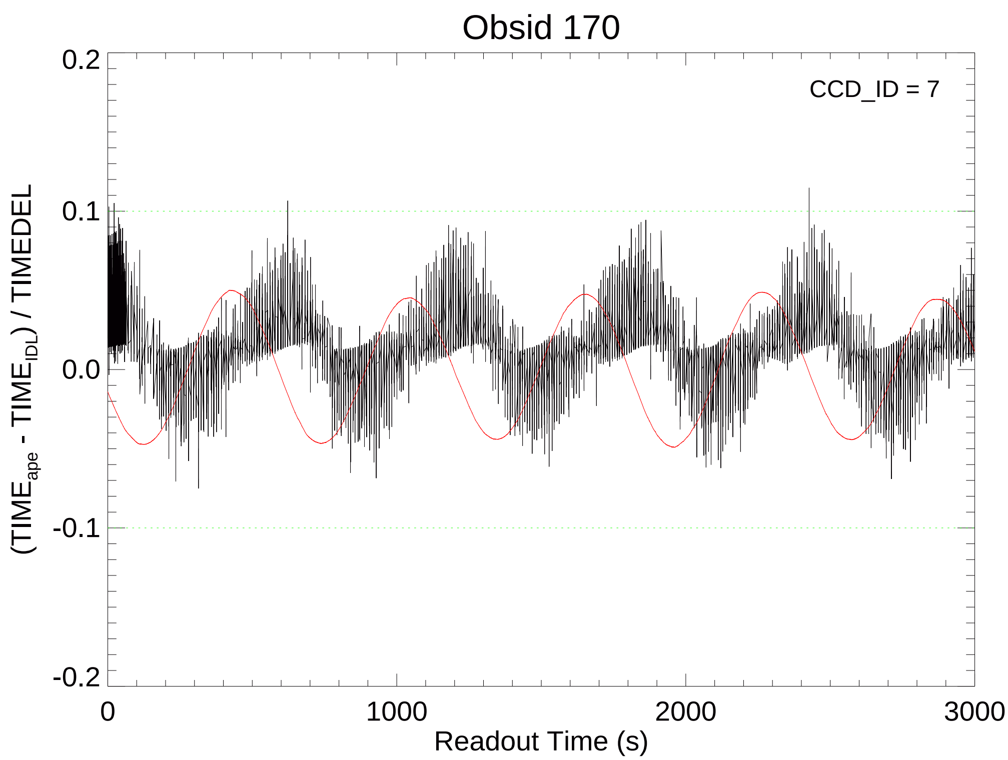

Fig. 4. The first 3 ks of data shown in figure 3. The red curve shows a plot of the (scaled) dither motion in right ascension.

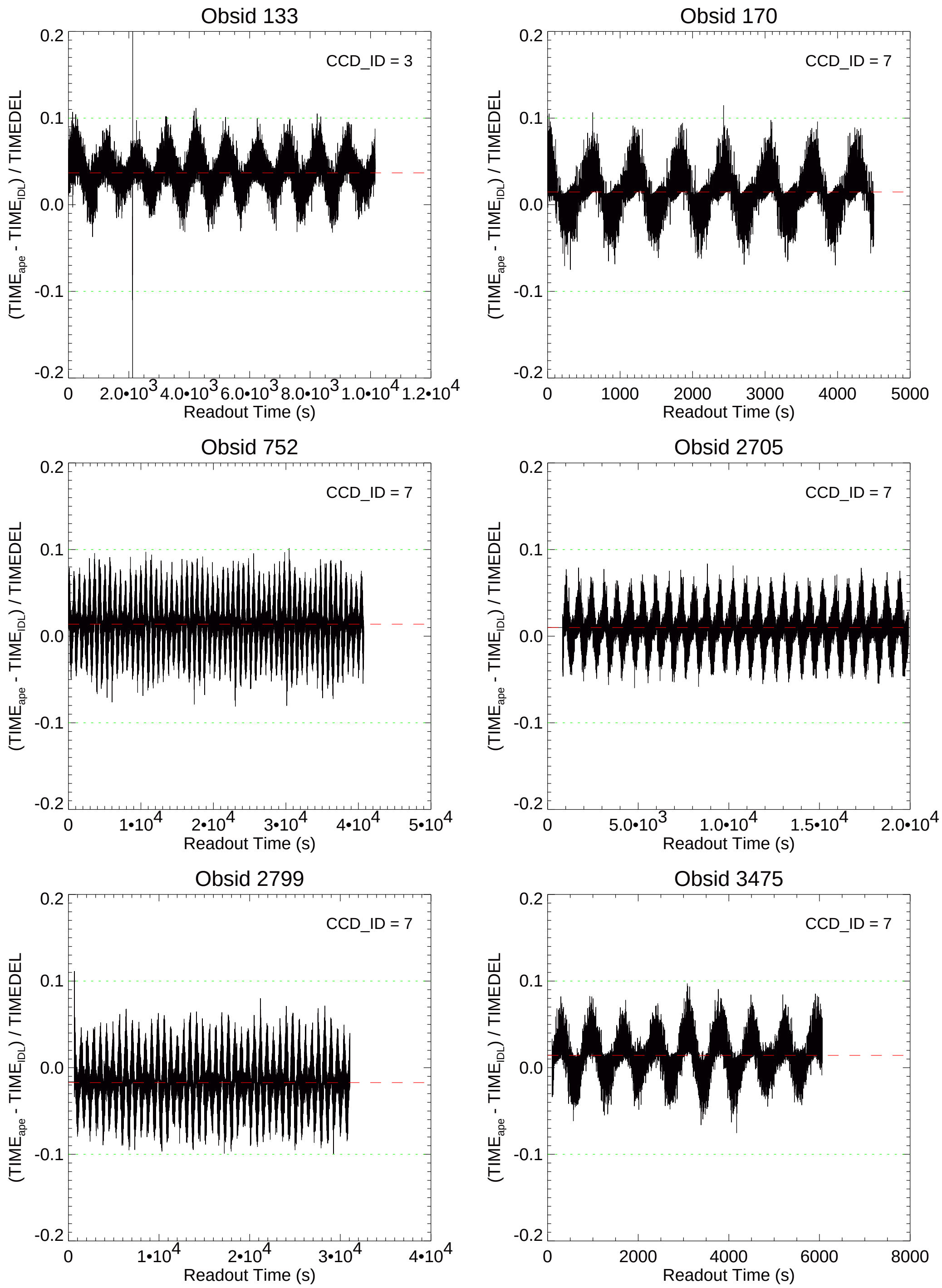

Fig. 5. The differences between the times of arrival computed using acis_process_events and the times computed using some IDL procedures for six continuous-clocking mode observations.

Summary

- $\ddot\smile$ The times of arrival can be computed using acis_process_events. (The code—CIAO 2.3—is expected to become public this month.) In the future, all new observations will have the times of arrival computed by default as part of the standard pipeline processing. Older observations will be reprocessed.

- $\ddot\smile$ The systematic and statistical uncertainties in the implementation of equation 1 are about 0.1 ms (i.e. $0.04 \times$ TIMEDEL) and 0.05 ms (i.e. $0.02 \times$ TIMEDEL), respectively. These uncertainties are much smaller than the uncertainty due to the point-spread function. The total 1 σ uncertainty in the times of arrival is about 3.6 ms (i.e. $1.3 \times$ TIMEDEL).

- $\ddot{-}$ The coordinates RA_TARG and DEC_TARG may need to be modified before computing the times of arrival to obtain the most accurate absolute times of arrival.

- $\ddot{-}$ The name of the column TIME_RO must be explicitly specified as part of the output if the readout times are to be written to the output file (in addition to the times of arrival).

- $\ddot{-}$ Time intervals with no (or bad) aspect information should be excluded from timing analyses.

- $\ddot\frown$ It is not possible to easily rerun acis_process_events to modify the times of arrival using a file that already contains the times of arrival. (This problem will be fixed in a future release of the software.)