Chandra Timing Analysis

(See the Following Useful Web Sites)

http://asc.harvard.edu/ciao/threads/lightcurve/
http://asc.harvard.edu/ciao/threads/filter_ltcrv/
http://asc.harvard.edu/ciao/why/ccmode.html
http://asc.harvard.edu/ciao/threads/acisctoa/
http://asc.harvard.edu/ciao/threads/axbary/
http://space.mit.edu/CXC/analysis/SITAR

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Hey?! Isn't That RXTE's Job? Yes, but … *Chandra* Can:

- **Observe Crowded Fields**
- **Observe the 0.1 – 2 keV Energy Band**
- **Obtain 10^{-5} Hz – 10^{-3} Hz (not since EXOSAT!)**
- **Faint Objects (*Single* Photons Matter!)**

And It Can do msec Timing Too!

Normalizing Power as $(RMS)^2/Hz$:

$(\text{Noise Limit} * df)^{1/2} = (2/R)^{1/2} (1 + B/R)^{1/2} (df / T)^{1/4}$,

i.e., RMS limit in *averaged* frequency bin, where:

- R = Signal Count Rate
- B = *Constant* Background Count Rate
- T = Total Observation Length
- *df* = Width of Frequency Bin

Example: T = 40 ksec,

RMS Limit $\sim 10\% \, R^{-1/2} (1 + B/R)^{1/2} (df / 1 \text{ Hz})^{1/4}$

Reducing Background Can Really Help!

Fundamental Times: ACIS, TE Mode

- **Frame Time (from *Proposers Guide*):**
  T (msec) = (41 + 0.040 * q)*m + 2.84*n + 5.2 ,
  q = # of rows from readout
  m = # of active chips
  n = # of rows read
- **Reality: Frame Time is *Integer* Multiple of 0.1 sec (0.2 – 10 sec) + 41.04 msec**
- **Caveat: Images are Transferred to Frame Store (Quasi-) Serially, so up to a 5*41.04 msec Delay Between Chips**
- **Event Times are *Middle* of Frame Time**

Fundamental Times: ACIS, TE Mode

- **Frames Take 41.04 msec to Transfer to Frame Store, so a Given Amount of (Uniform) Deadtime is Expected**
- **Charge Moved at 40 msec/row, which Gives the Potential for Very Fast Timing of Readout Streaks**
- **(Sources that bright will otherwise be difficult to deal with…)**

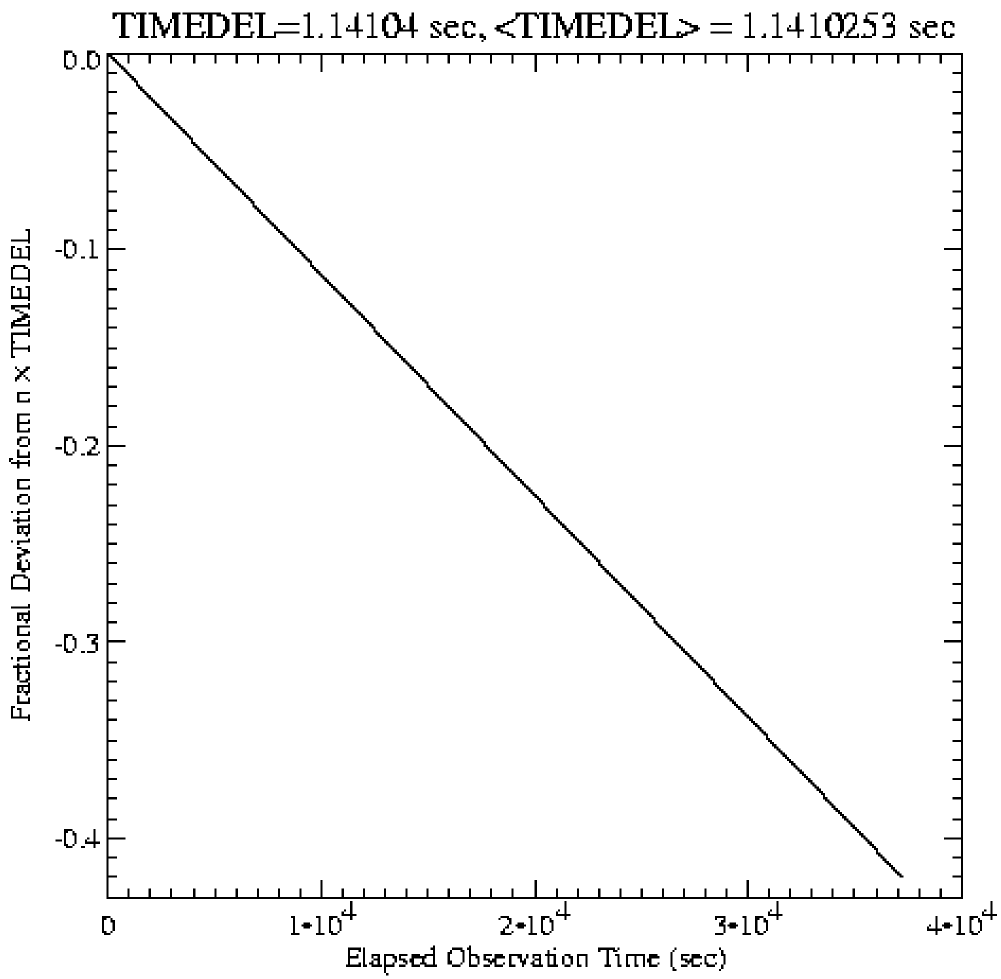
Fundamental Times: ACIS Keywords

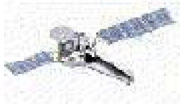
- MJDREF = 50814.
- TIMEZERO = 0. (i.e., corrections to TIME)
- TSTART = start time in sec. from MJDREF
- TSTOP = stop time in sec. from MJDREF
- TIMEPIXR = 0.5 (i.e., times in middle of frame)
- TIMEDEL = *Nominal* Frame Time
- EXPTIME = *Nominal* "Live Time" per Frame
- DTCOR = EXPTIME/TIMEDEL
- ONTIME_n = per chip quantities
- LIVETIME_n
- EXPOSURE_n

Fundamental Times: ACIS Keywords

- **ACIS Clock *Stable* to 1 Part in 10^5, ~1 sec Drift over 100 ksec Observation**
- **Spacecraft Clock, after Corrections from Ground, *Accurate* to μsec Levels**
- **Time between Frames ~ TIMEDEL X (1 +/- 10^{-5})**
- **Plotting Exposure Number vs. Time Usually Gives Linear Correlation**
- **If You Want to be Ultra-careful, Bin by EXPNO.**
  (Caveat: You'll Have to Handle GTI's Yourself)

Fundamental Times: ACIS, TE Mode





Fundamental Times: ACIS, TE Mode

- **Event Time is *Terrestrial Time*, Referenced to:**
  MJD = 50814.0 (January 1, 1998)
  MJD = Julian Date – 2,400,000.5
  (TJD = MJD – n * 10,000. *Don't Use!*)
- ***XMM*: Same Reference MJD**
- ***RXTE* Referenced to:**
  MJD = 49353.000696574074 (January 1, 1994)
  (fraction is ~ 1 min., i.e. TT vs. UTC)
- ***ASCA* is Referenced to:**
  MJD = 48988.0 (January 1, 1993)

Check FITS Headers!

None of These Times are Barycentered! (Requires Orbital Ephemeris; *axbary*)

- **Useful Links for Understanding/Converting:**
- **NIST Time Glossary -**

  http://www.bldroc.gov/timefreq/

- **Date Conversion Utility -**

  http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/DateConv/dateconv.pl

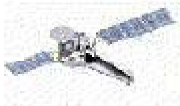
- **Look at *ahelp* file for *axbary***

Fundamental Times: ACIS, CC Mode

- **Rows are Read Out Every 2.85 msec**
- **Chips are Read in Parallel**
- **Time is Read Out Time, *Not* Arrival Time. (Read out delay from aim point, modulo dither, etc.) Thread Exists to Correct Aimpoint Times**
- **Generalization to CC-Gratings Observation Will be Forthcoming**
- **40 msec row shift "deadtime" still applies**

Fundamental Times: HRC-S

- **HRC-I Wiring Problem Limits Time to ~ 4 msec on Average**
- **HRC-S Can Achieve 16 μsec Accuracy**
- **Faster Timing than ACIS, but more severe Telemetry Limits (184 cps), and Higher Backgrounds**
- **But, no Deadtime, and HRC-S is Linear Up to at Least 5 cps for a Point Source (i.e., no pile-up)**

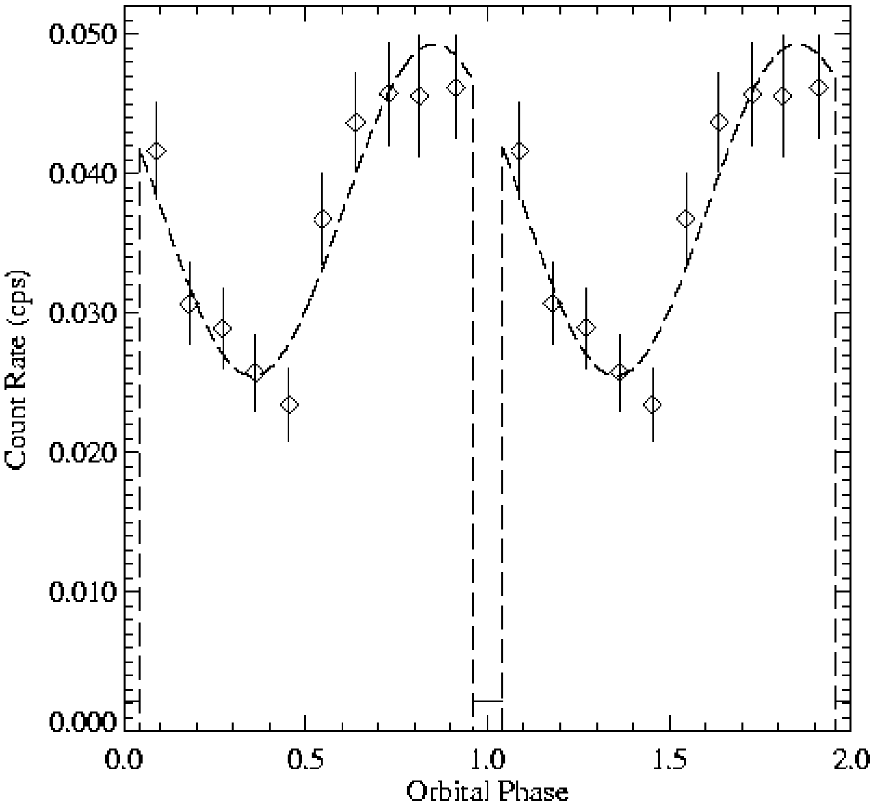


Tools at Your Disposal:

- CIAO Tools: *dmextract* (replaces *lightcurve)*, *axbary*, *apowerspectrum*, threads on filtering lightcurves, barycentering, correcting times, etc.
- Data products can be further analyzed with *S-Lang* (e.g., *SITAR*), *IDL*, *XRONOS*…
- More in Development
    - S-lang script to create gratings lightcurves (Followed by CIAO Tool Version)
    - SITAR (Bayesian Blocks) in Sherpa
    - Period/Epoch Folding in SITAR

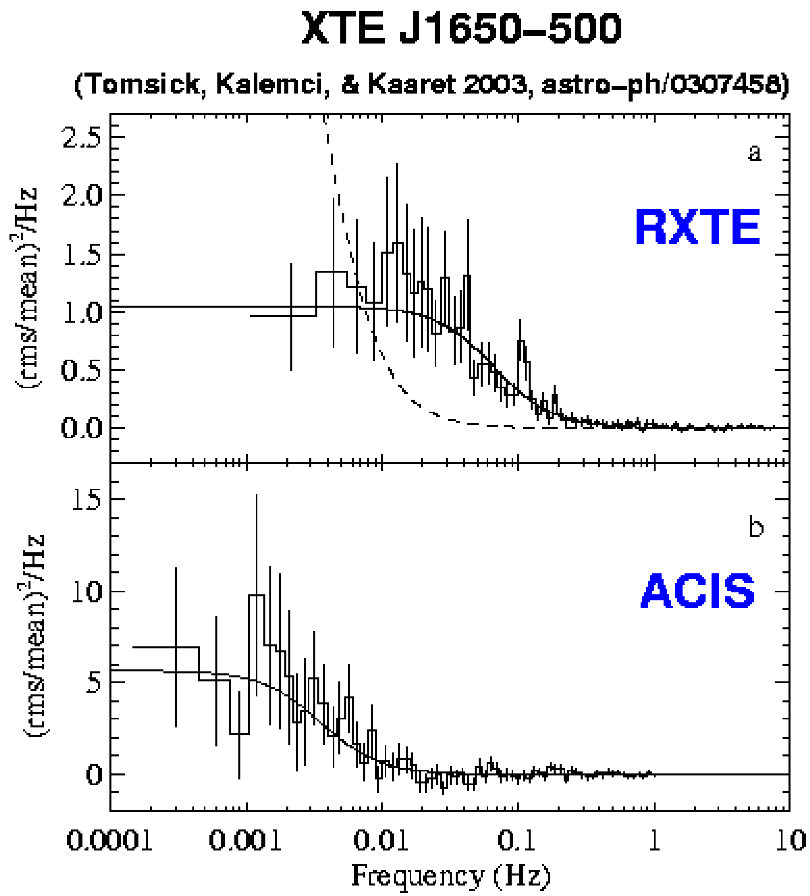
Self-Promoting Example:

- ***lightcurve*** **(now would use *dmextract*) corrected with *axbary*, allows comparison to previous observations**
- **Folded Spectrum Created with *CIAO* Tools (*psextract* with explicit time ranges)**
- ***0 Background!***
  df **~ 5 x 10^{-5} Hz , RMS > 4%**
- ***Single photon events*** **used to determine rapidity of eclipse, yielding limits on source size**

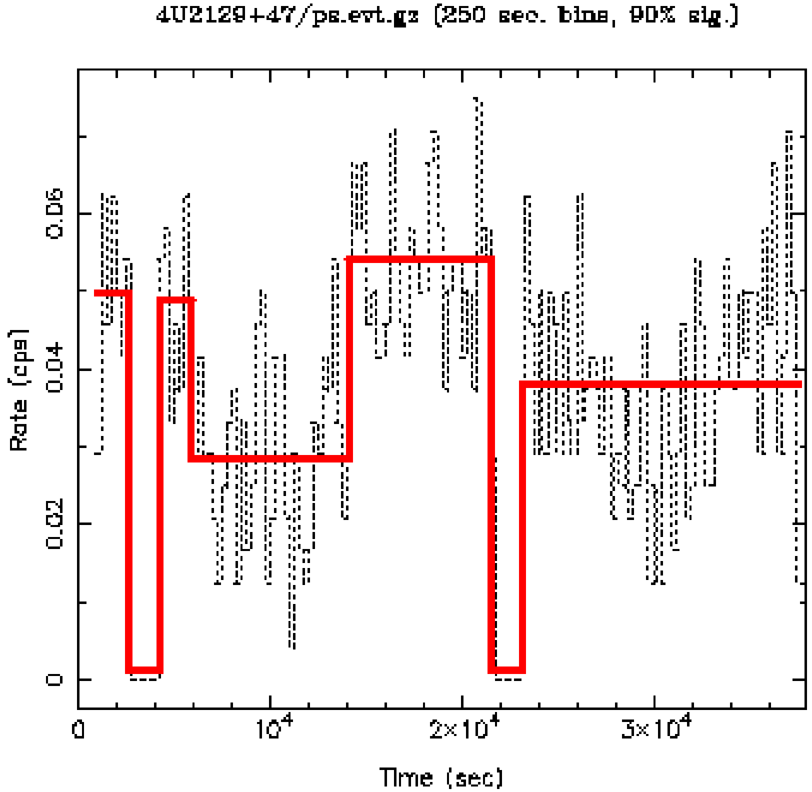


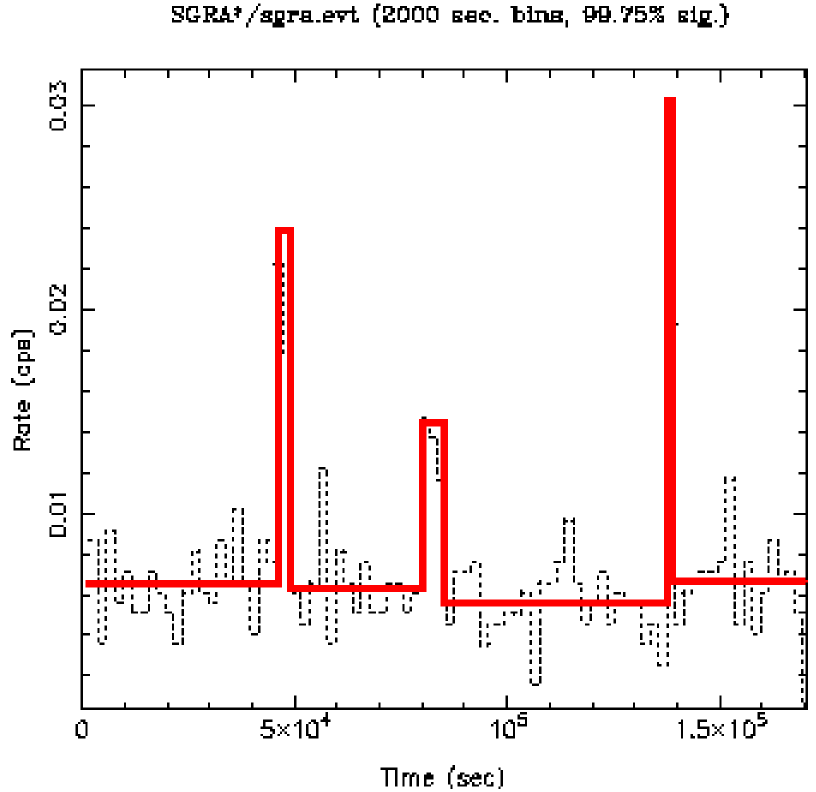
Example of ACIS Power Spectrum

- **Tomsick, Kalemci, & Kaaret (2003), astro-ph/0309741**
- **PSD created on Exposure Number**
- **Deadtime and pile-up affect variability estimates & expected Poisson noise level**



"Bayesian Blocks" from SITAR





Programmable: Mike Muno has looked at 20,000 lightcurves From 2,300 Galactic Center Sources

See http://space.mit.edu/CXC/analysis/SITAR for Examples

Other Examples Have Included:

- **Crab Pulsar (Easily Detected)**
- **RX J185635-375 (astro-ph/0204159):**
  Strong Upper Limits to Pulse Fraction
- **Important Caveat/Strong Suggestion:**
  Bin on Integer Multiples of “Natural” Time Unit,
  Watch Out for Instrumental Time Scales (dither, etc.)