Absolute Time Calibration

Arnold Rots
CXC

Time in CXC Data Products

- Time is defined by:
  - TIMESYS keyword: Time scale used – default TT
  - MJDREF keyword: Reference time in MJD (TIMESYS)
  - TIMEZERO keyword: Clock correction – default zero
  - TIME column: Elapsed time since MJDREF
  - TIMEUNIT keyword: Unit of TIME and TIMEZERO – default ‘s’
- Additional information:
  - TSTART, TSTOP keywords: Time range of the HDU in elapsed time
  - DATE−OBS, DATE−END keywords: Time range in ISO−8601 format (2002−11−07T16:12:45.814)
  - DATE keyword: Creation date and time of data product in **UTC**

Time Definition

- Events are tagged with a timestamp that represents a (virtual) clock on the spacecraft that runs synchronously with TT on the geoid.
- More precisely, that clock is defined such that if a signal were transmitted from the spacecraft at spacecraft time T_S, it should be received at the geocenter at $T_S + \tau$, where τ is the geometric path length (in seconds) between the spacecraft and the geocenter.
- An extra complication is that the spacecraft clock information is not transmitted directly, but is to be inferred from the structure of the telemetry (using the old−fashioned major and minor frame formats) that is clocked by the spacecraft clock.

Uncertainties

- Clock calibration – sources of error:
  - Uncertainty in the position of the spacecraft, leading to an uncertainty in τ of up to 100 μs, according to requirement
  - Measurement errors (at most a few μs)
  - Short term clock noise (presumed less than a few μs)
  - “Instrumental” delays (under investigation – Jeff Holmes, William Davis)
  - Relativistic orbit effects (eccentricity, gravitational potential; < few μs)
- Converting event time stamps to absolute time (e.g., TDB):
  - Time stamp precision (16 μs for HRC in timing mode, 3 ms for ACIS in CC mode, frame time for ACIS in TE mode)
  - Uncertainty in spacecraft orbit ephemeris (up to 100 μs, see above)
  - Lunar and planetary ephemeris (DE200/DE405); consistency required
  - Error in source direction (user’s responsibility)

Absolute Calibration (Celestial)

- Pulsar observations

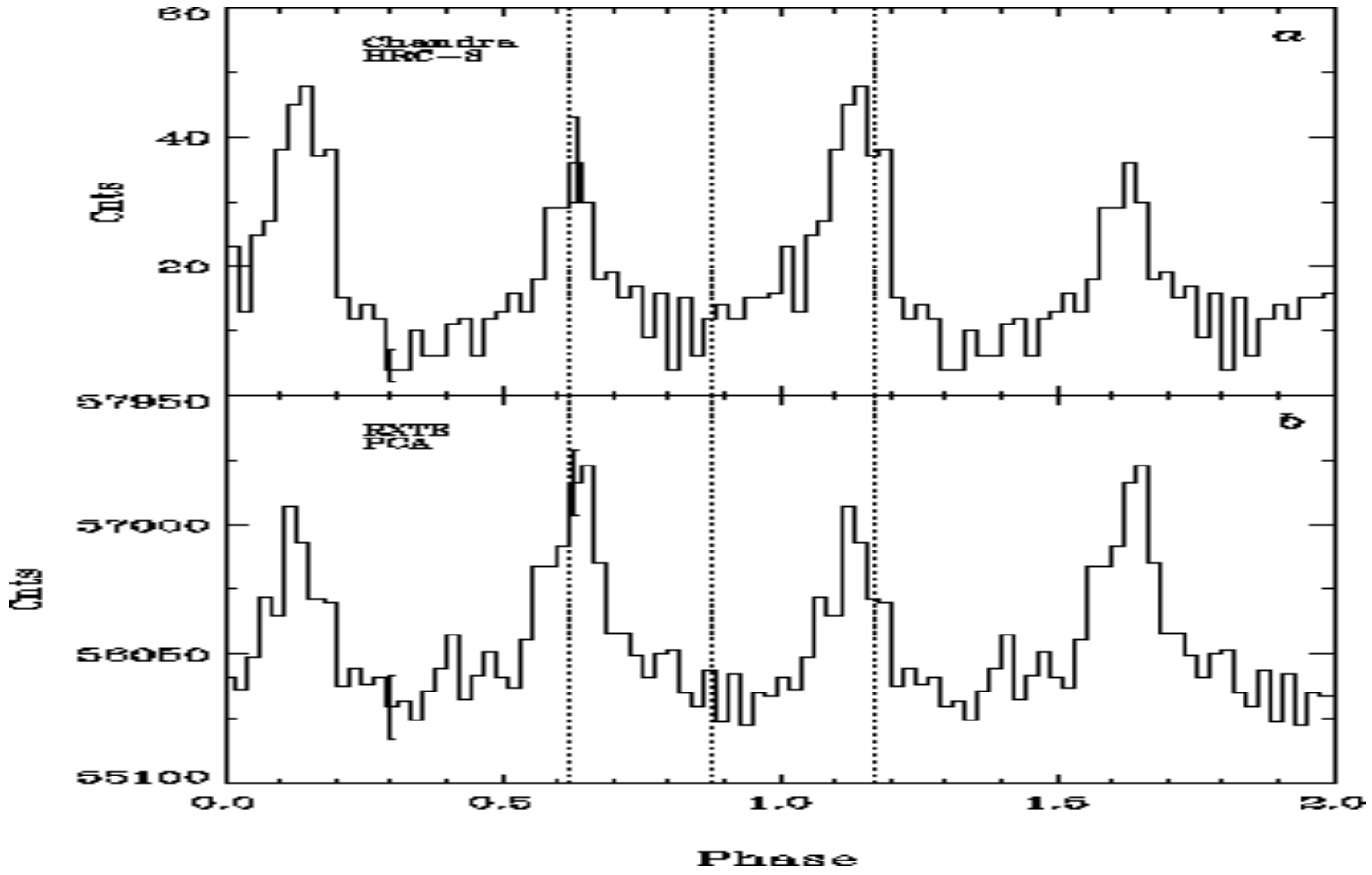
  Requirements:

- At least two pulsars with different periods to avoid ambiguities
- One of these needs to allow timing measurements to about 10 μs
  - Combination of period, pulse profile, and pulsed flux
- Accurate timing ephemerides – simultaneous multi−mission observations (RXTE, HETE II)
- Repeat this calibration a few times to check consistency

Relevant Observations to Date

- Crab pulsar – HRC before Timing Mode (Allyn Tennant):
  CXO clock runs 200 ±70 μs slow
- PSR B0540−69: irreconcilable, but not well−coordinated; possibly affected by clock/ephemeris anomaly
- Rapid burster – ACIS CC (Herman Marshall and Allyn Tennant):
  CXO clock correct within 23 ms
- PSR J0218+423 – 2.3 ms pulsar, HRC Timing Mode (Lucien Kuiper) around epoch 2002.0:
  CXO clock runs 105 ±20 μs slow
  (in principle ±*n*×2.3 ms)

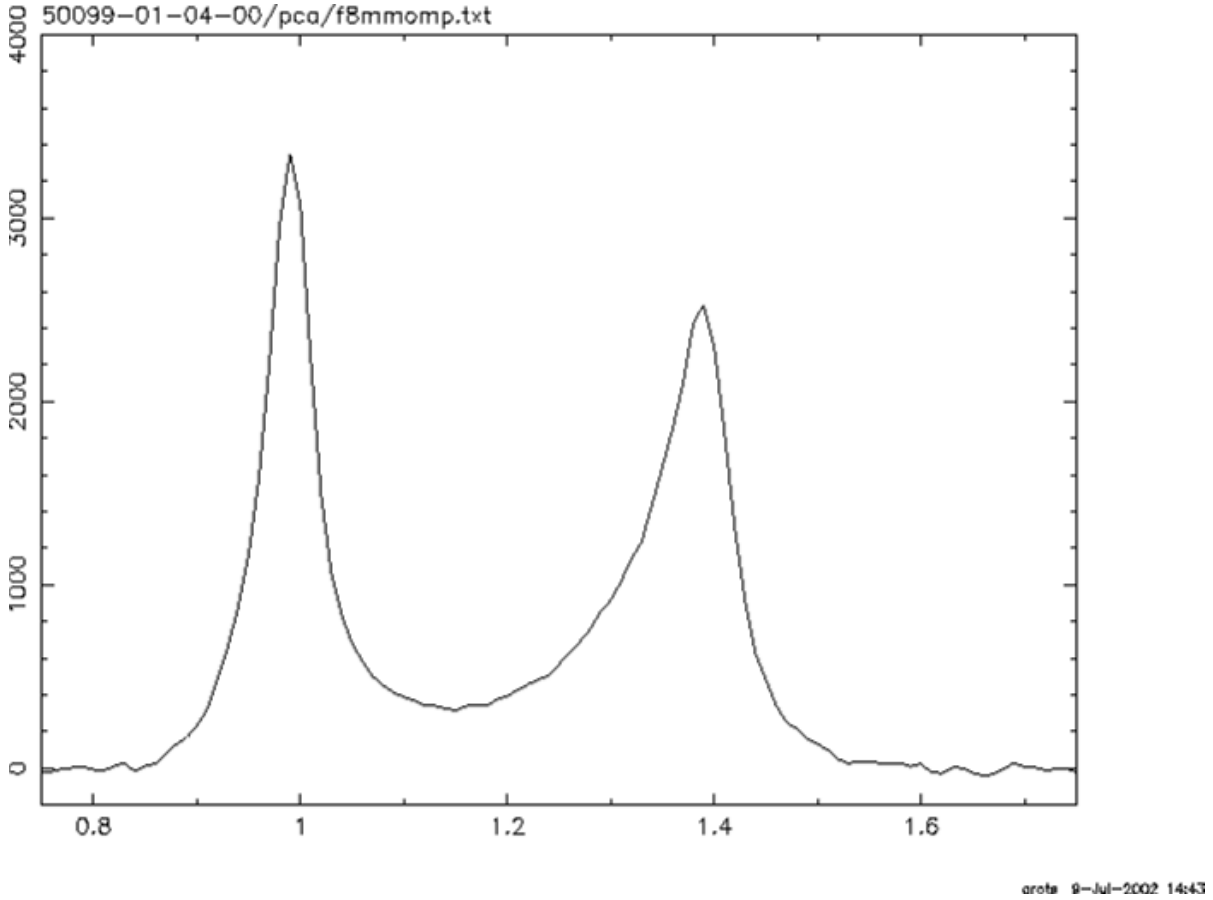
PSR J0218+423 – CXO and RXTE



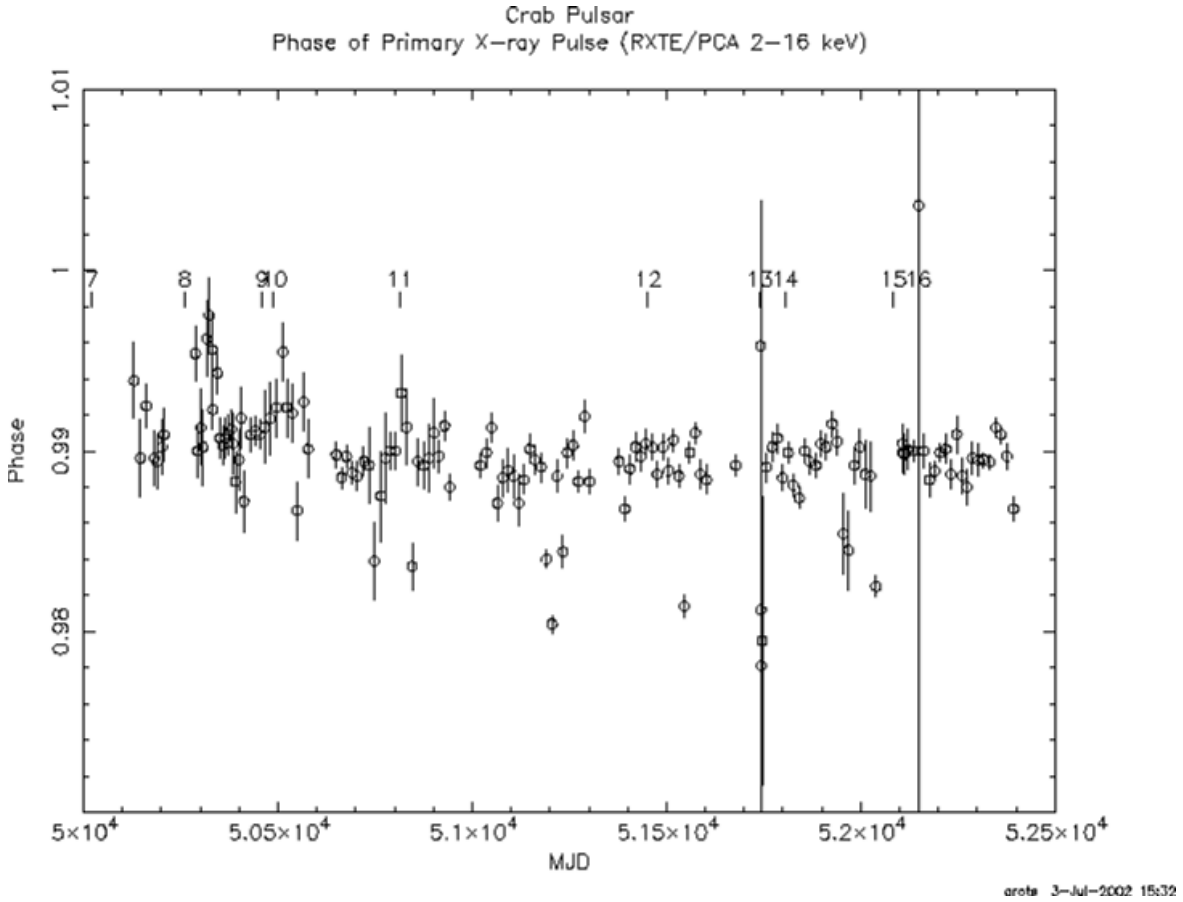
What's Next?

- Resolve instrumental delays
- Repair clock/ephemeris anomalies
- Revisit the old data
- Execute a program of new observations; I would propose:
  - Two pulsars are being monitored continuously by RXTE:
    PSR B1509−58 (150 ms) and the Crab (33 ms)
  - Use PSR B1509−58 to resolve multiple Crab period ambiguities (just to make sure)
  - Use the Crab pulsar to measure clock error to ~20 μs and monitor it over a period of a year
  - Careful positioning required, of course
  - Depending on results, perform final ~5 μs calibration; e.g., PSR B1821−24

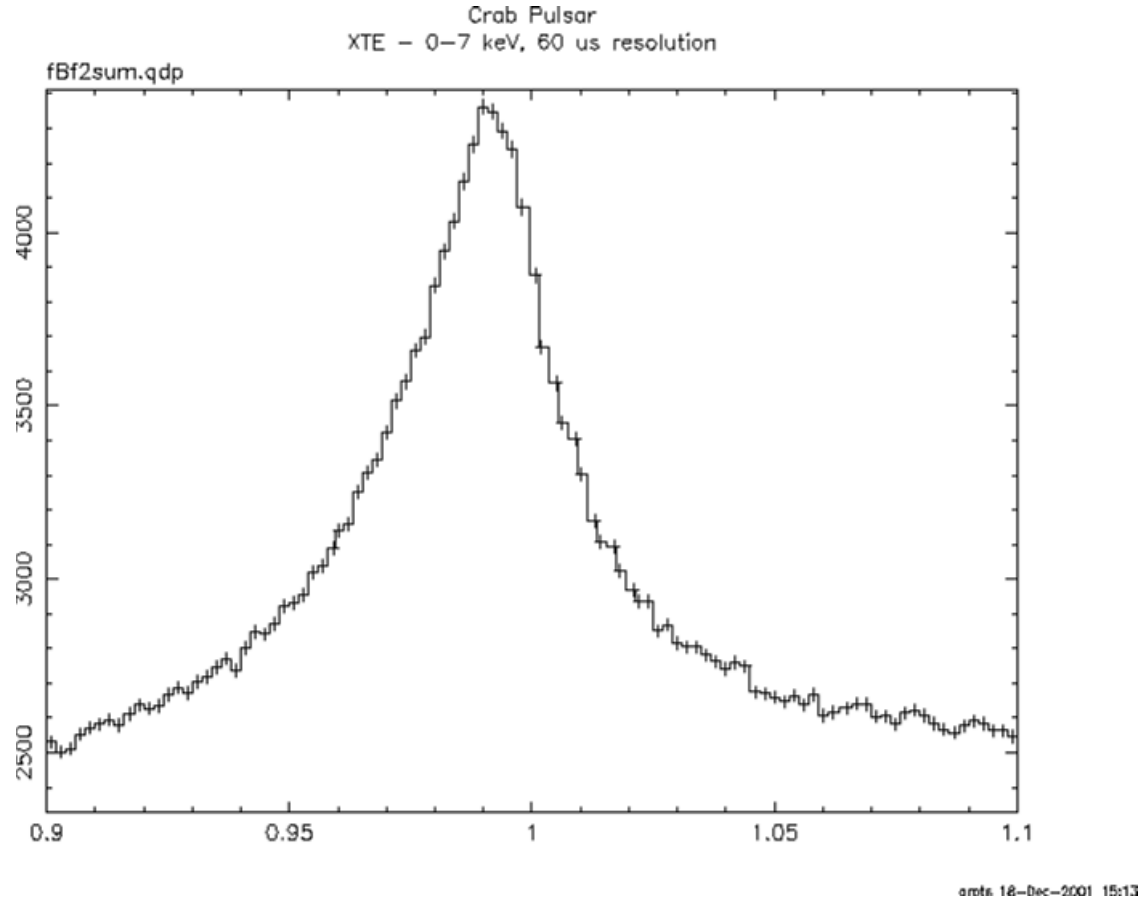
Crab Pulse Profile



Crab Pulsar: X−ray Phase



Crab Pulsar: Main Pulse at 60 µs Resolution



Crab Pulsar: Main Pulse at 30 μs Resolution