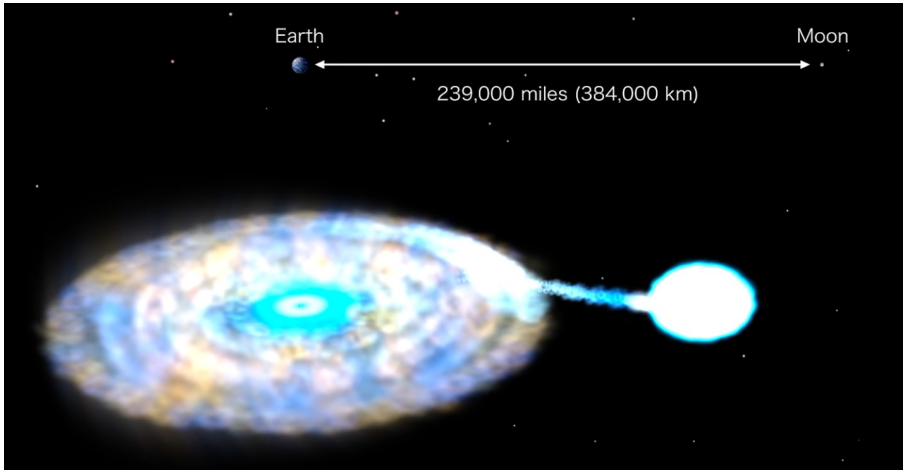
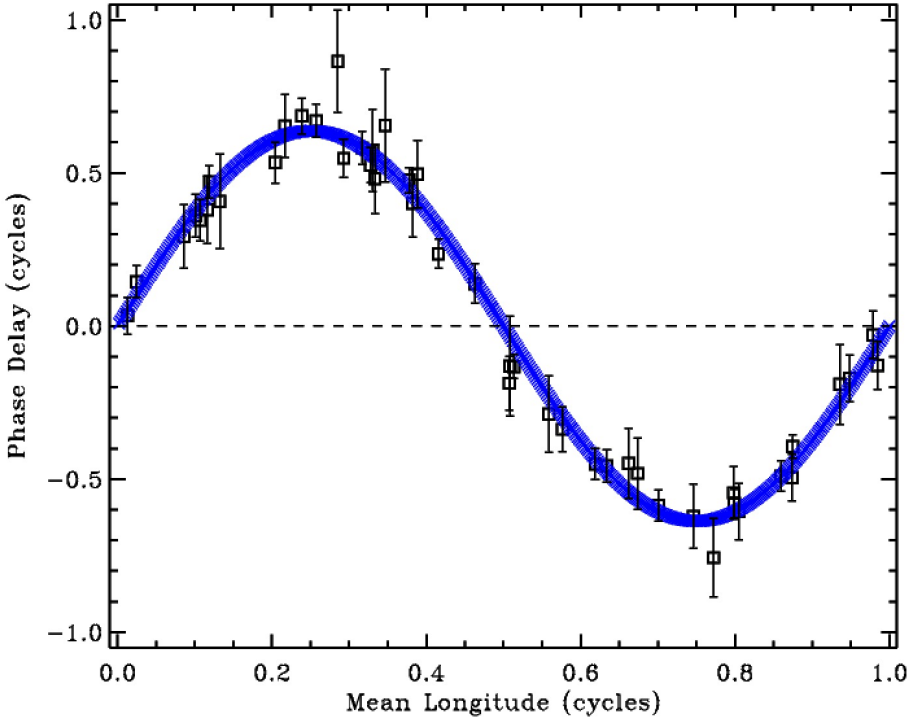
Some Notes on Timing Analyses and NICER Data

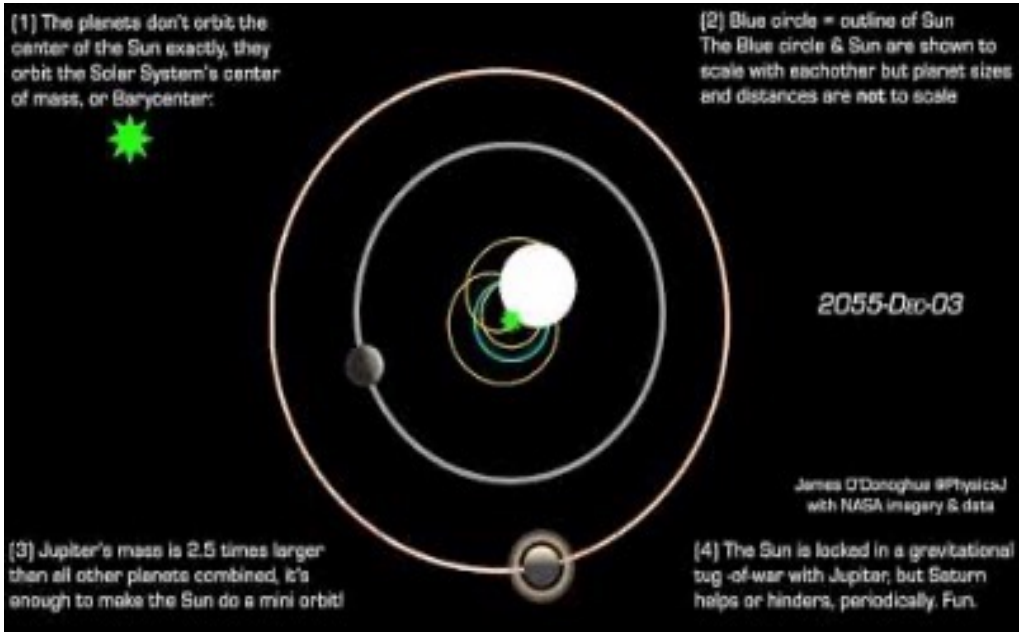
- Doing barycentric corrections.
- Being mindful of the possibility of “fragmented” or “shredded” good time intervals (GTIs).





NICER observations of 38 min binary IGR J17062-6143 (Bult et al. 2021; Strohmayer et al. 2019).

Solar System Barycenter: Convenient "Inertial" Reference Frame



- For precise timing studies of pulsars, which often are members of a binary system, must correct NICER-measured arrival times to a local inertial frame (solar system barycenter).
- This "removes" time delays/advances associated with Earth's (and NICER's) orbital motions within our solar system.
- Also, to compare measurement times made with other observatories, often want "uniform" reference time.

Geometric delays (order of magnitude): LEO satellite orbits, +- 25 ms (~95 min timescale)
There are smaller relativistic corrections as well. Earth – Sun, +- 8 min (year timescale)

Use *barycorr* tool to do barycenter correction

```
gs66-sable:/local/data/sable1/stroh/nicer_data/maxij1803(54) pset barycorr
Input file name:[maxij1803.evt]
Output file name:[maxij1803_bary.evt]
Orbit ephemeris file(s) (or @filename):[maxij1803.orb]
(Swift) Clock Correction File[CALDB]
Right Ascension (decimal degrees):[-] 270.76171
Declination (decimal degrees):[-] -29.83013
Reference frame (ICRS or FK5):[FK5] ICRS
Ephemeris to use (or DEFAULT to use refframe):[DEFAULT] JPLEPH.430
Create/overwrite BARYTIME column in output file?:[no]
Tolerance level (in seconds) for orbit file glitches (ignored for Swift)[3.0]
Do you want to delete any existing output files?:[no]
Write parameter history block?[yes]
Verbosity level (0:5) [3]
Mode:[ql]
gs66-sable:/local/data/sable1/stroh/nicer_data/maxij1803(55)
```

Inputs for barycenter calculation:

- Source Position (Coordinates, RA, and DEC, J2000)
- Solar System EPHEMERIS file
- NICER orbit file
- NICER Input (event data) file.

See: fhelp barycorr

barycorr infile='maxij1803.evt' outfile='maxij1803_bary.evt' orbitfiles='maxij1803.orb' ra=270.76171 dec=-29.83013 refframe='ICRS' ephem='JPLEPH.430' barytime=no clobber=yes

Running *barycorr* from an OBSID Directory

barycorr infile='xti/event_cl/ni1034100101_0mpu7_cl.evt' outfile='xti/event_cl/ni1034100101_0mpu7_cl_bary.evt' orbitfiles='auxil/ni1034100101.orb.gz' ra=256.56770 dec=-61.71144 refframe='ICRS' ephem='JPLEPH.430' barytime=no clobber=yes

```
gs66-sable:/local/data/sable1/stroh/nicer_data/igrj1706v2/1034100101(115) barycorr infile='xti/event_cl/ni1034100101_0mpu7_cl.evt' outfile='xti/event_cl/ni1034100101_0mpu
7_cl_bary.evt' orbitfiles='auxil/ni1034100101.orb.gz' ra=256.56770 dec=-61.71144 refframe='ICRS' ephem='JPLEPH.430' barytime=no clobber=yes
**** Running barycorr v2.13 ****
barycorr: shell ftcopy infile='xti/event_cl/ni1034100101_0mpu7_cl.evt' outfile='xti/event_cl/ni1034100101_0mpu7_cl_bary.evtworkfile14196' copyall=YES clobber=YES chatter=
0 history=NO
barycorr: running hdaxbary -i 'auxil/ni1034100101.orb.gz' -f xti/event_cl/ni1034100101_0mpu7_cl_bary.evtworkfile14196 -jpleph 430 -ra 256.56770 -dec -61.71144 -ref ICRS
barycorr: shell hdaxbary -i 'auxil/ni1034100101.orb.gz' -f xti/event_cl/ni1034100101_0mpu7_cl_bary.evtworkfile14196 -jpleph 430 -ra 256.56770 -dec -61.71144 -ref ICRS 2>&
1
===> No barycenter correction applied to HDU 0
     TIMESYS is
<=== Finished after 11 HDUs
hdaxbary: Using JPL Planetary Ephemeris DE-430
hdaxbary: Using JPL Planetary Ephemeris DE-430
hdaxbary: Using JPL Planetary Ephemeris DE-430
hdaxbary: Using JPL Planetary Ephemeris DE-430
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hdaxbary: Using JPL Planetary Ephemeris DE-430
hdaxbary: Using JPL Planetary Ephemeris DE-430
hdaxbary: Using JPL Planetary Ephemeris DE-430barycorr: exited with status 0
barycorr: shell ftchecksum infile='xti/event_cl/ni1034100101_0mpu7_cl_bary.evtworkfile14196' update=yes datasum=YES chatter=0
barycorr: shell ftcopy infile='xti/event_cl/ni1034100101_0mpu7_cl_bary.evtworkfile14196' outfile='xti/event_cl/ni1034100101_0mpu7_cl_bary.evt' copyall=YES clobber=YES cha
tter=0 history=NO
barycorr: barycorr successfully completed

gs66-sable:/local/data/sable1/stroh/nicer_data/igrj1706v2/1034100101(116)
```
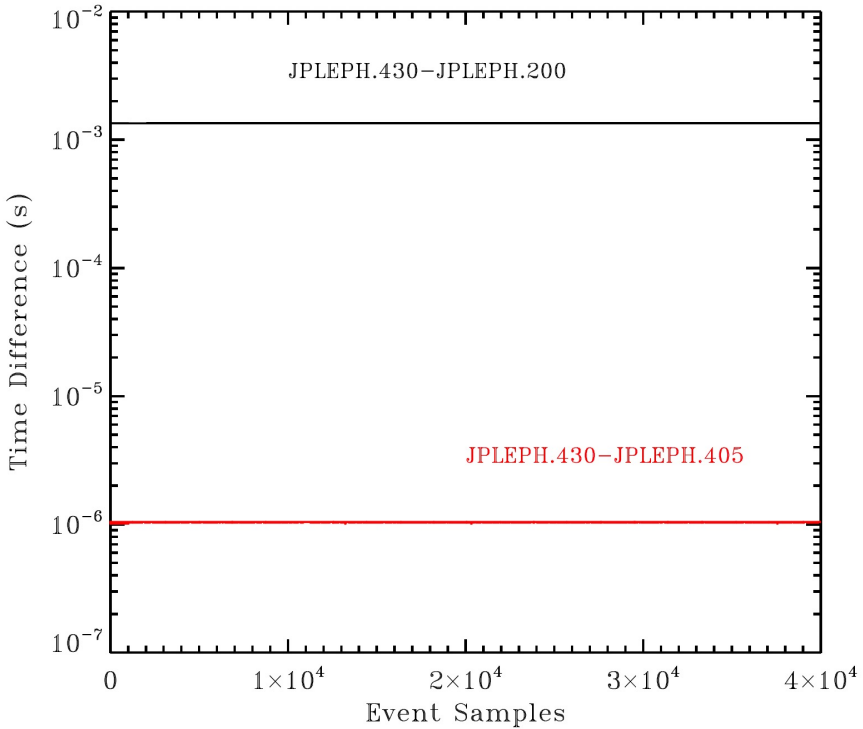

What Ephemeris Should I Use?



- *barycorr* works with a number of JPL planetary ephemerides. Controlled with parameters refframe and ephem.
- Recommend using modern ephemeris, such as DE430 or DE405. Set,
  refframe='ICRS' ephem='JPLEPH.430' or
  refframe='ICRS' ephem='JPLEPH.405'
- Can still use older version DE200, for comparison with previous work or historical results. Set,
  refframe='FK5' ephem='JPLEPH.200'

Defaults: if refframe='ICRS' and ephem='default', you get DE405. If refframe='FK5' and ephem='default' you get DE200.

Running *barycorr:* barytime option

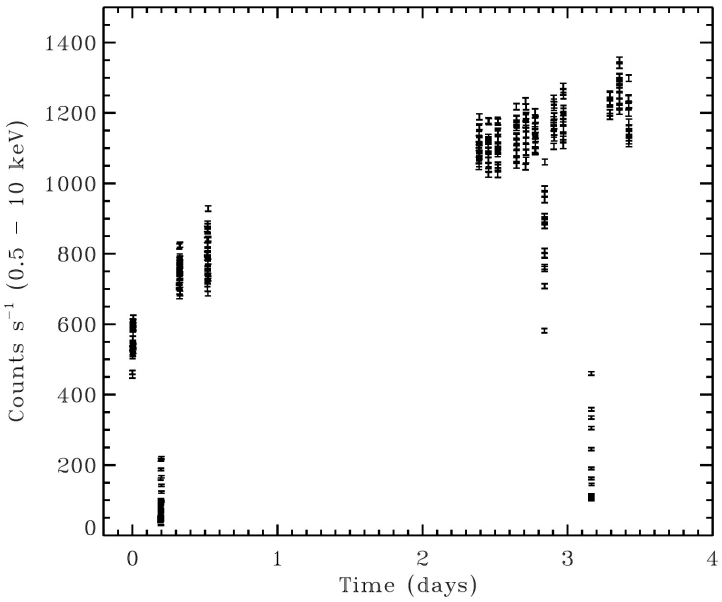
```
TREFPOS = 'BARYCENTER'          / Time reference position
TREFDIR = 'RA_OBJ,DEC_OBJ'      / Keywords of reference direction
More?[ ]
PLEPHEM = 'JPL-DE430'           / Solar system ephemeris used for baryctr corr.
HISTORY TOOL :axBary - 2.14                                          ASC0000
HISTORY PARM :infile=maxij1803_bary.evtworkfile72733                 ASC0001
HISTORY PARM :outfile=maxij1803_bary.evtworkfile72733                ASC0002
HISTORY
HISTORY START PARAMETER list for barycorr_2.13 at 2021-05-06T15:15:22
HISTORY
HISTORY P1 infile = maxij1803.evt
HISTORY P2 outfile = maxij1803_bary.evt
HISTORY P3 orbitfiles = maxij1803.orb
HISTORY P4 clockfile = CALDB
HISTORY P5 ra = 270.76171
HISTORY P6 dec = -29.83013
HISTORY P7 refframe = ICRS
HISTORY P8 ephem = JPLEPH.430
HISTORY P9 barytime = no
HISTORY P10 tolerance = 3.0
HISTORY P11 clobber = yes
HISTORY P12 history = yes
HISTORY P13 chatter = 3
HISTORY P14 mode = ql
HISTORY END PARAMETER list for barycorr_2.13
```

Time-related keywords updated in the output file.

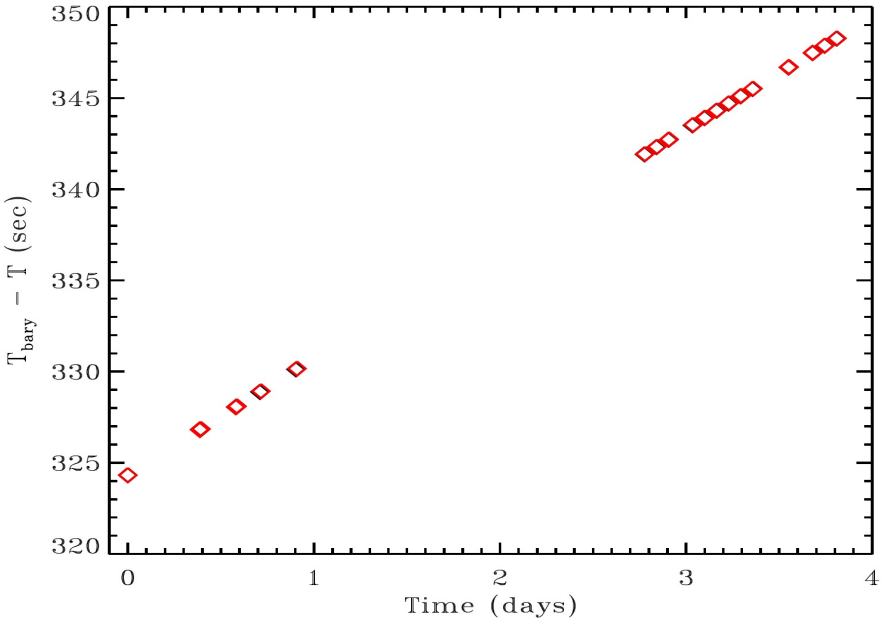
Recommend: barytime='no'
Updates TIME column in new file (don't overwrite the old file!).
Also updates time keywords and GTI extensions!
barytime='yes' will add new column

```
OBJECT  = 'MAXI_J1803-298'      / Object/target name
EQUINOX =               2000.0 / [yr] Equinox of celestial coord system
RADECSYS= 'ICRS    '            / Coordinate Reference System
RA_NOM  =             270.5723 / [deg] R.A. of nominal aspect point [J2000]
DEC_NOM =            -29.80504 / [deg] Dec. of nominal aspect point [J2000]
RA_OBJ  =       2.70761710E+02 / Right Ascension used for barycenter corrections
DEC_OBJ =      -2.98301300E+01 / Declination used for barycenter corrections
TIMESYS = 'TDB     '            / All times in this file are TDB
MJDREFI =                56658 / TDB time reference; Modified Julian Day (int)
More?[Yes]
MJDREFF = 0.000777592592592593 / TDB time reference; Modified Julian Day (frac)
TIMEREF = 'SOLARSYSTEM'         / Times are pathlength-corrected to barycenter
TASSIGN = 'SATELLITE'           / Time assigned by clock
```

Barycenter Correction Applied to MAXI J1803 Data

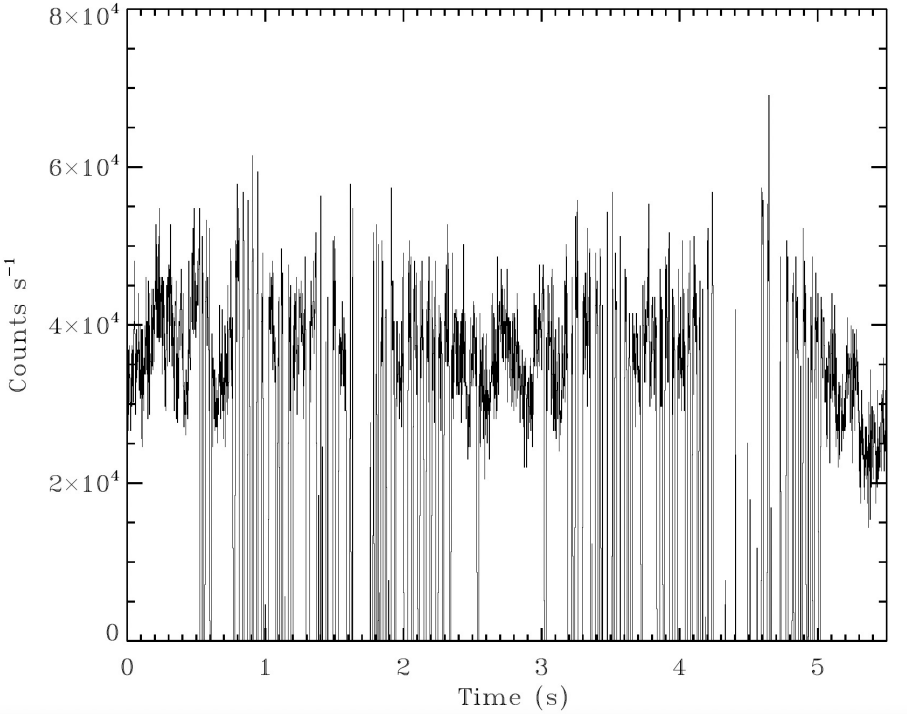


Bonus light curve! Source shows absorption dips (Atels #14588, 14606)



Difference between barycenter time and local (spacecraft) time. Magnitude set by Earth – Sun separation (in lt-sec), and drift due to Earth orbital motion.

Fragmented GTIs and Timing Analysis

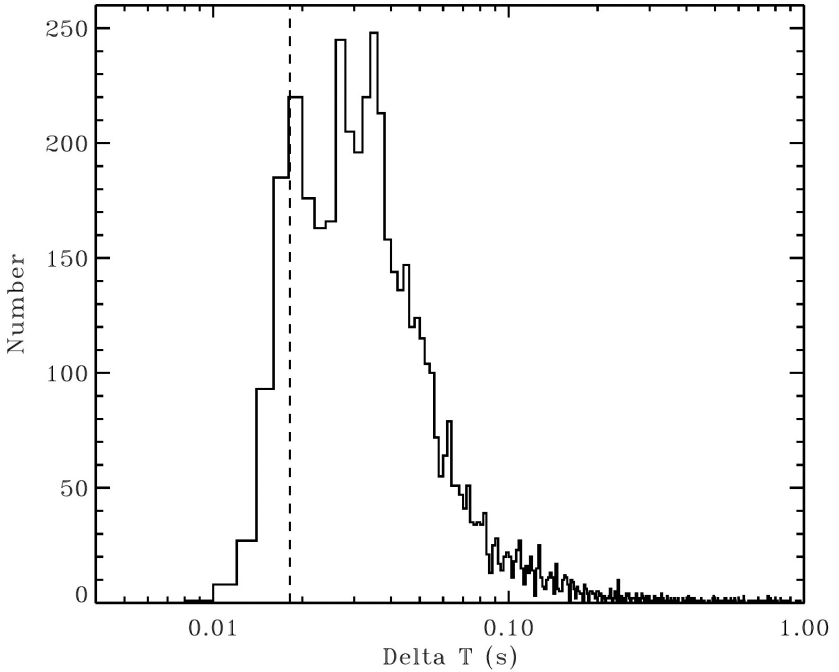


Light curve (histogram) from binning events in 1/512 s bins in a bright segment of data from MAXI J1820+070 (obsid: 1200120107).

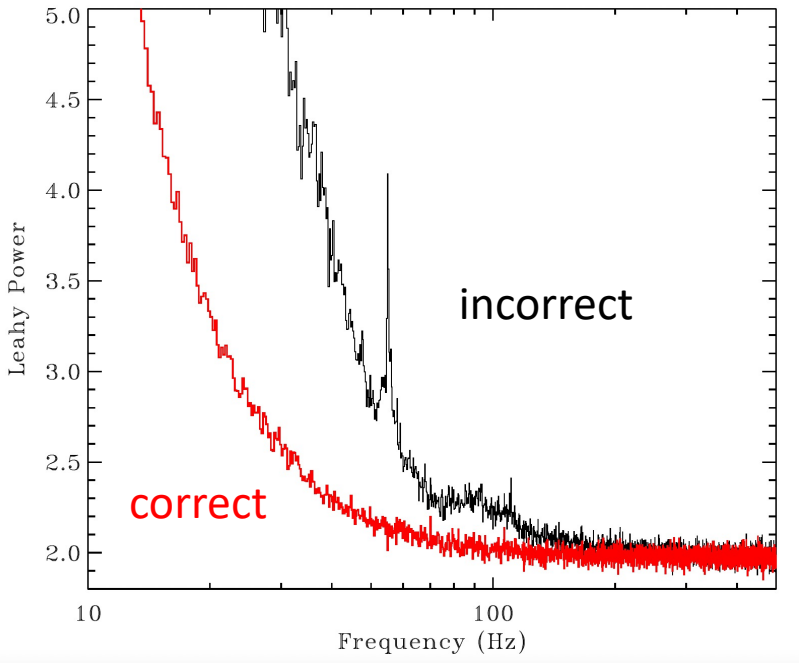
- For bright targets (see MAXI J1820+070, left) telemetry saturation can limit the data throughput, leading to many short GTIs.
- Optical loading (”undershoots”) and high background event rates can also result in selection criteria being violated frequently.
- These conditions can lead to so-called GTI “fragmentation” or “shredding,” meaning there are, perhaps many, very short GTIs.

- For very bright targets can turn off some detectors on each MPU (but has to be planned).
- Can vary selection criteria to try and obtain fewer, longer GTIs.

Fragmented GTIs and Timing Analysis



OBSID: 1200120107. Extreme case with 5912 GTIs! Above shows a histogram of the time separations between the GTIs.



Timing analysis must consider the "window function." Power spectrum of light curve which includes data gaps can show spurious peaks due to the presence of nearly periodic gaps.

Considerations for Timing with NICER

- Be mindful of and check your GTIs! If you are used to long, uninterrupted Chandra and/or XMM-Newton exposures, then NICER may sometimes come as a surprise with sometimes shortish exposures.
- If timing is your *primary* goal, and not spectroscopy, then you may be able to live with the small variations in the energy spectral calibration that could result from less stringent selection criteria. So, experiment with different selections, these could perhaps reduce issues with GTI fragmentation.
- Be cautious of observations of "new" sources where the target position may not yet be precisely known. Typical pointing jitter when the target is not on-axis could introduce spurious modulation of the observed count rate.

Can review thread on definition of TIME in NICER data files.

https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/time/