# Presence of a third body orbiting around XB 1916-053

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# What we know on XB 1916-053

- The source shows type-I X-ray bursts
- The source shows dips in its light curve
- The source does not show eclipses in its light curve

The presence of type-I X-ray bursts implies that the compact object is a neutron star.

The absence of eclipses and the presence of dips implies the inclination angle of the system is between 60° and 80°.

From the recurrence of the dips the orbital period was estimated to be close to 50 min.



# What we know on XB 1916-053

- The orbital period close to 50 min predicts a companion star mass close to 0.1 $M_{sun}$ ($m_2$=0.11$P_h$)

- In highly compact system the companion star is a degenerate star (e.g. Rappaport et al.; 1987)

- The companion star is helium dominated (Nelemans et al; 2006)

- The study of the flux-peak during the photospheric radius expansion of the type-I X-ray bursts of XB 1916-053 predicts that the distance to the source is d= 8.9±1.3 kpc, assuming a He-dominated companion star (Galloway et al; 2008)

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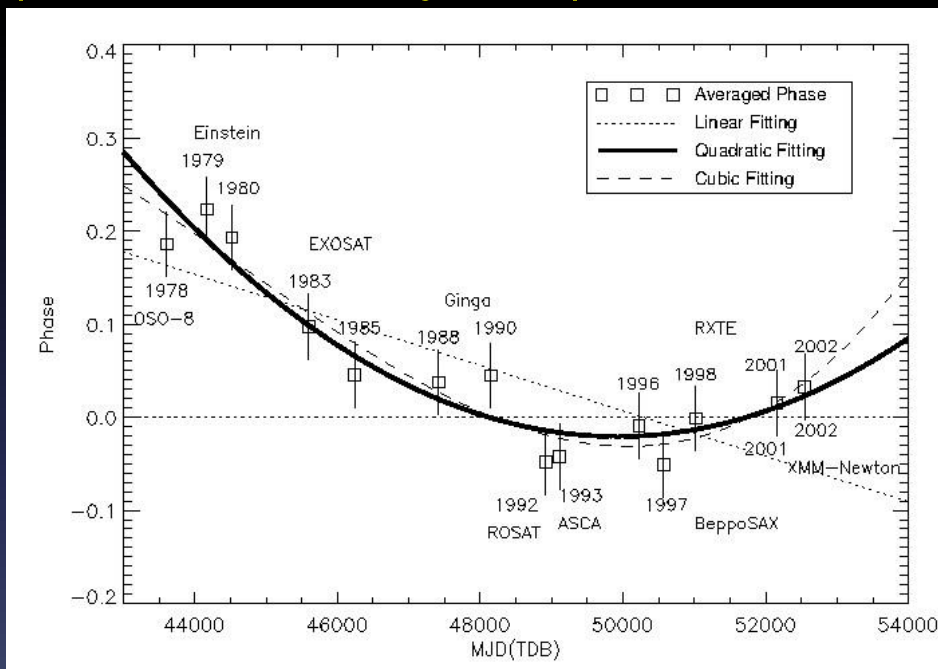
# The Old Orbital Ephemeris of XB 1916-053

(Hu, Chou & Chung; 2008)




The orbital ephemeris was obtained using data from 1978 (*OSO-8*) to 2002 (*XMM*-Newton)

$$T_0 = 50123.0087(4)\ MJD$$

$$P_0 = 3000.6511(7)\ s$$

$$\dot{P} = 1.5(3) \times 10^{-11}\ s/s$$

The cubic function does not improve statistically the fit.

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# Our Dataset

We used all the available archival data obtaining 27 light curves.
Our data span the time interval from 1978 to 2014.

Folding the 27 light curves we analyse 27 dips.

20 dips cover the time interval from 1978 to 2002 (the same times spanned by Hu, Chou & Chung (2008) in their work).

7 dips are obtained from light curves taken in the time interval from 2003 to 2014. These light curves were taken with several observatories and Instruments:

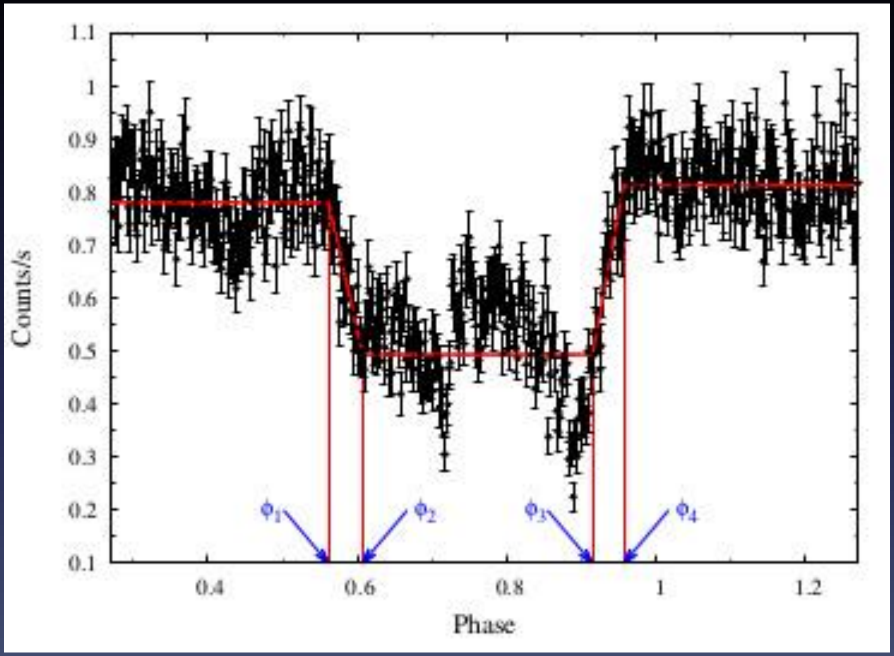
*INTEGRAL*/JEM-X; *Chandra*/HEG, *Chandra*/LEG, *Suzaku*/XIS0, *Swift*/XRT, *Rossi*-XTE/PCA.



# How we obtain the dip arrival times

We folded the light curves using as trial period   $P_0$=3000.6511 s

The folding epoch $T_{fold}$ of each light curve was the average time between its start and stop time.




We fit the dip-shape using a step-and-ramp function.

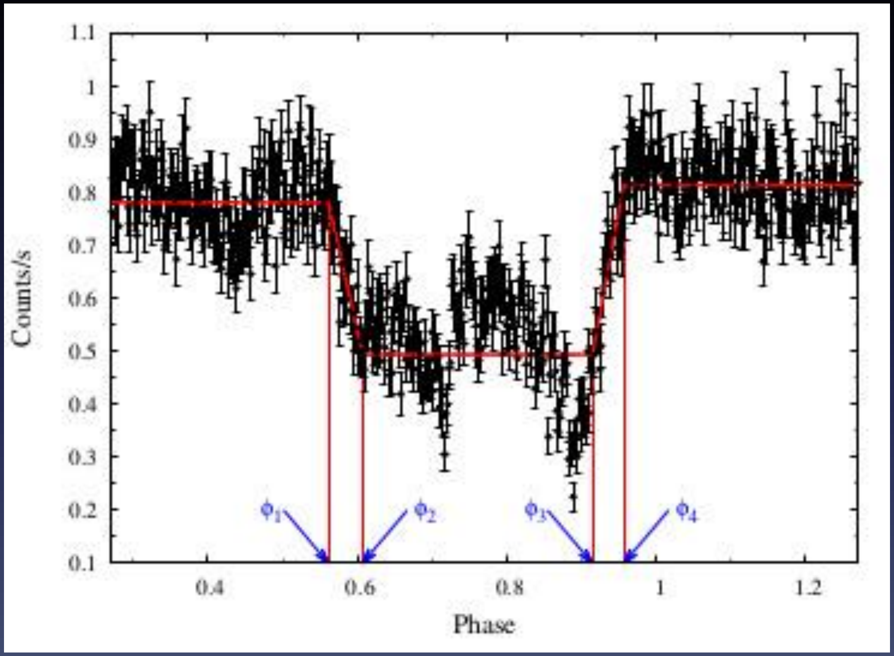
This model involves seven parameters: the count rate before, during, and after the dip, called $C_1$, $C_2$, and $C_3$, respectively;

the phases of the start and stop time of the ingress ($\varphi_1$ and $\varphi_2$), and, finally, the phases of the start and stop time of the egress ($\varphi_3$ and $\varphi_4$).

# How we obtain the dip arrival times

We folded the light curves using as trial period $P_0$=3000.6511 s

The folding epoch $T_{fold}$ of each light curve was the average time between its start and stop.




We fit the dip-shape using a step-and-ramp function.

The dip arrival time $T_{dip}$ is

$$T_{dip} = T_{fold} + \varphi_{dip} P_0$$

where

$$\varphi_{dip} = (\varphi_1+\varphi_4)/2$$

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# How we obtain the delays associated with dip arrival times

We adopted as epoch of refence  T0 = 50123.00873 MJD

| Point | Dip Time (MJD;TDB) | Cycle | Delay (s) |
|---|---|---|---|
| 1 | 43 609.4168(12) | -187 551 | 772 ± 74 |
| 2 | 44 168.2535(5) | -171 460 | 792 ± 28 |
| 3 | 44 523.2941(5) | -161 237 | 641 ± 42 |
| 4 | 45 594.7744(3) | -130 385 | 449 ± 18 |
| 5 | 46 209.6271(13) | -112 681 | 193 ± 112 |
| 6 | 46 351.7778(9) | -108 588 | 352 ± 52 |
| 7 | 47 414.193(2) | -77 997 | 162 ± 132 |
| 8 | 48 146.539(3) | -56 910 | 47 ± 182 |
| 9 | 48 913.6127(10) | -34 823 | −140 ± 59 |
| 10 | 49 109.1148(12) | -29 165 | −48 ± 76 |
| 11 | 50 174.7555(5) | 1 490 | −50 ± 46 |
| 12 | 50 310.6187(4) | 5 402 | −17 ± 37 |
| 13 | 50 566.3680(4) | 12 766 | −69 ± 39 |
| 14 | 51 001.3241(5) | 25 290 | −15 ± 40 |
| 15 | 51 043.7292(5) | 26 511 | −9 ± 45 |
| 16 | 52 074.0935(3) | 56 179 | 151 ± 29 |
| 17 | 52 183.7349(3) | 59 336 | 107 ± 28 |
| 18 | 52 183.7008(2) | 59 335 | 162 ± 19 |
| 19 | 52 542.2168(4) | 69 658 | 227 ± 39 |
| 20 | 52 542.2860(11) | 69 660 | 202 ± 98 |
| 21 | 52 957.9679(8) | 81 629 | 327 ± 69 |
| 22 | 53 224.6246(4) | 89 307 | 467 ± 34 |
| 23 | 54 048.3791(5) | 113 026 | 411 ± 39 |
| 24 | 55 367.45218(15) | 151 007 | 593 ± 13 |
| 25 | 56 459.9129(3) | 182 463 | 721 ± 20 |
| 26 | 56 853.6454(8) | 193 800 | 821 ± 67 |
| 27 | 56 949.84670(10) | 196 570 | 814 ± 8 |

Note — Epoch of reference 50 123.00873 MJD, orbital period 3 000.6511 s.

$$\frac{T_{dip} - T_0}{P_0} = k$$

$$\text{int}(k) = N \quad \rightarrow Cycle$$

$$frac(k) P_0 = Delay$$

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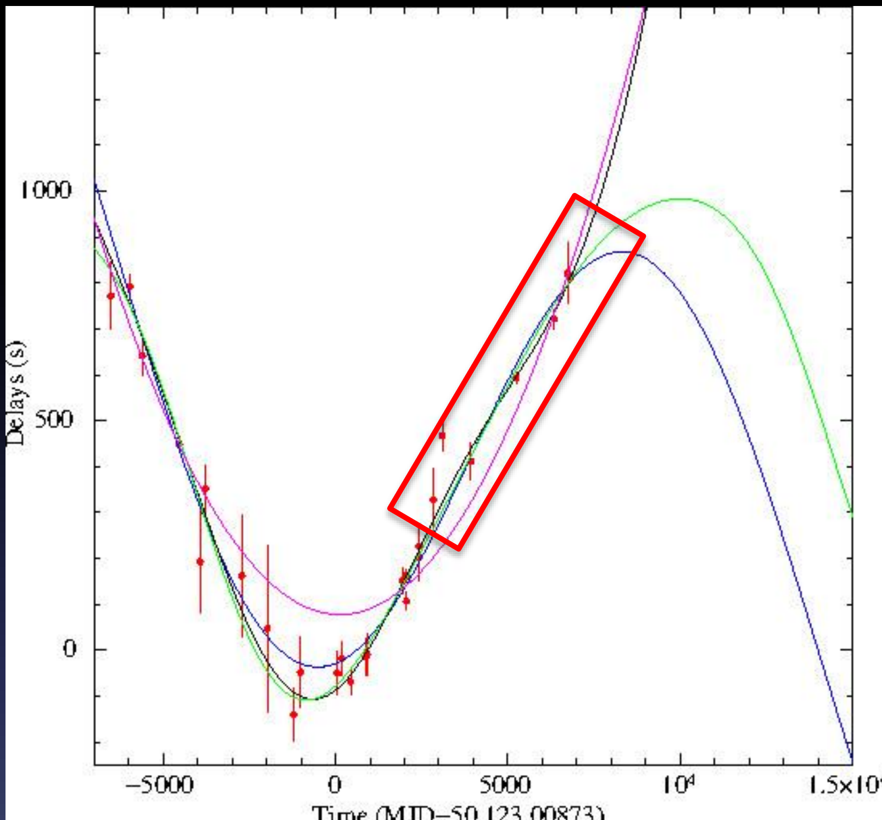
# Fitting the delays vs. time




Remember that in our analysis the trial epoch of reference $T_0$ and the trial period $P_0$ are those of the orbital ephemeris shown by Hu, Chou & Chung (2008)

In the red box the 7 points added in our work

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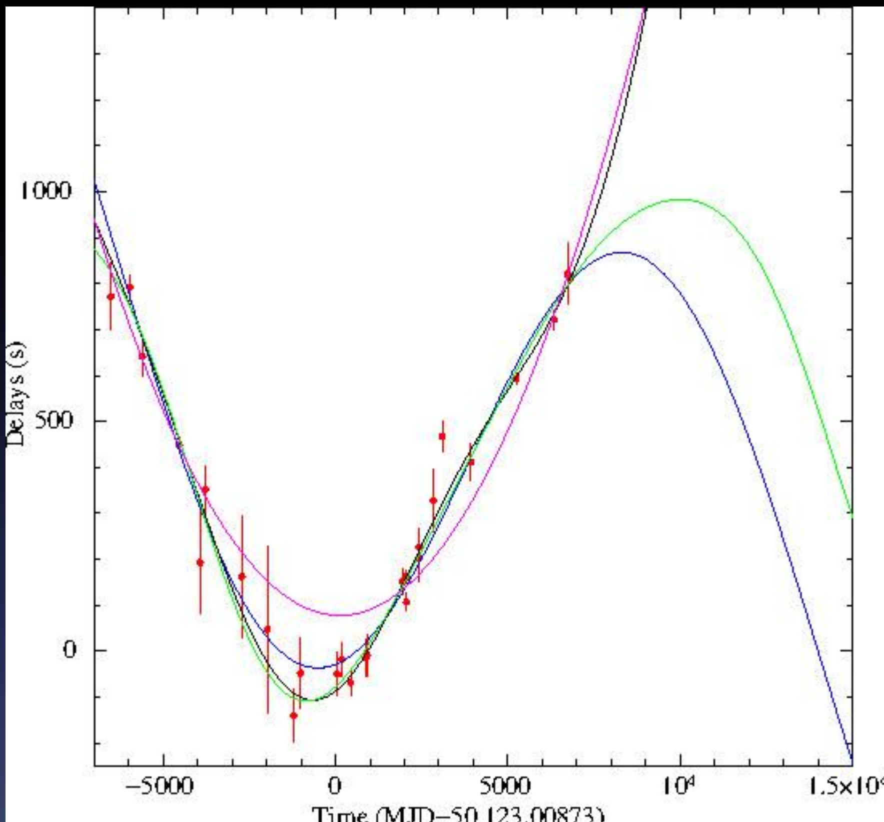
# Fitting the delays vs. time: the PARABOLIC (LQ) fit




Remember that in our analysis the trial epoch of reference $T_0$ and the trial period $P_0$ are those of the orbital ephemeris shown by Hu, Chou & Chung (2008)

Initially we fitted the data with a PARABOLIC function (MAGENTA curve in the plot)

$$y(t) = a + bt + ct^2$$

Where:

$$a = \Delta T_0$$

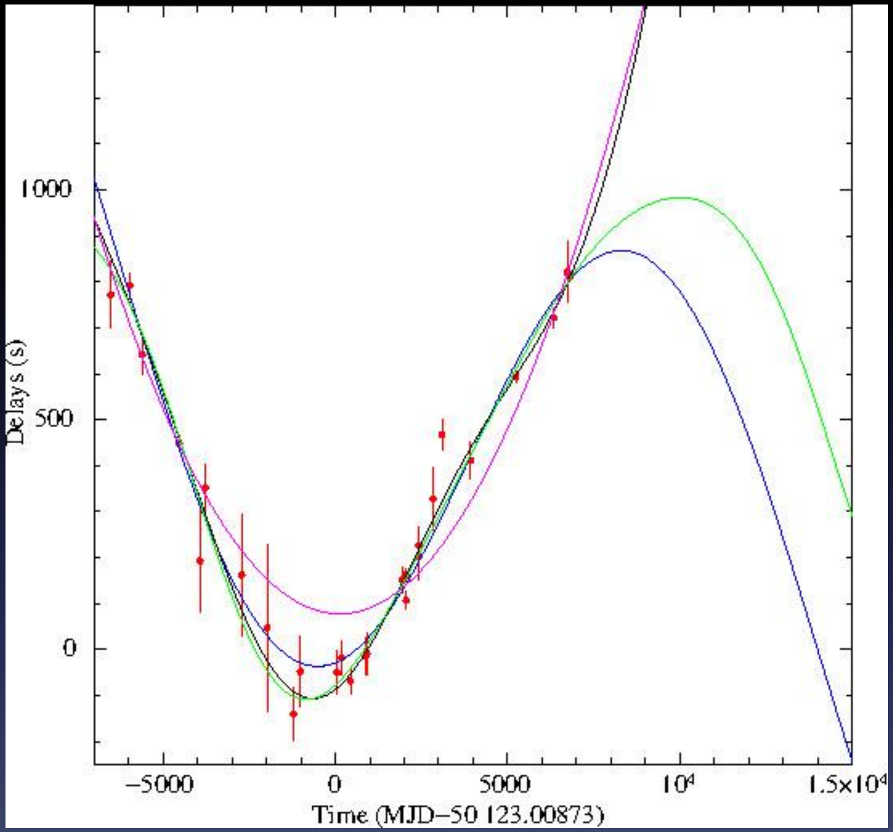
$$b = \Delta P / P_0$$

$$c = \tfrac{1}{2} \dot{P} / P_0$$

$$\chi^2(d.o.f.) = 194.6(24)$$



# Fitting the delays vs. time: the LINEAR+SINUSOIDAL (LS) fit



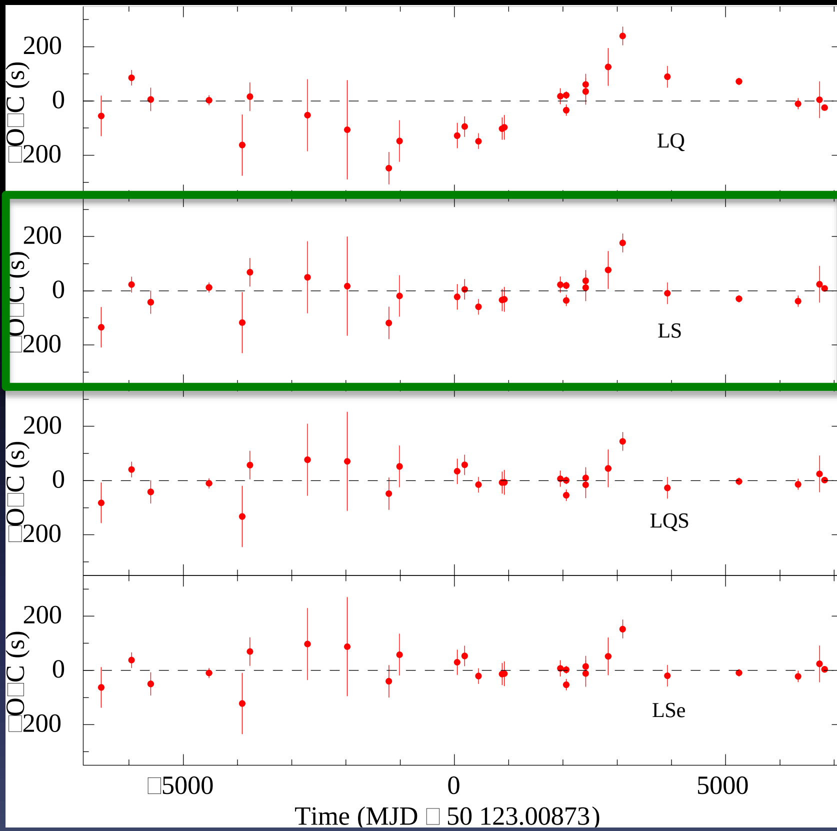

Remember that in our analysis the trial epoch of reference $T_0$ and the trial period $P_0$ are those of the orbital ephemeris shown by Hu, Chou & Chung (2008)

We fitted the data with a LINEAR+SINUSOIDAL function (BLUE curve in the plot)

$$y(t) = a + bt + A\sin[\frac{2p}{P_{\text{mod}}}(t - t_j)]$$

$$c^2(d.o.f.) = 63.7(22)$$

# Fitting the delays vs. time: the LINEAR+SINUSOIDAL fit




Remember that in our analysis the trial epoch of reference $T_0$ and the trial period $P_0$ are those of the orbital ephemeris shown by Hu, Chou & Chung (2008)

$$T_0 = 50123.01549(18)\,MJD$$

$$P_0 = 3000.6496(8)\,s$$

$$P_{mod} = 55.9 \pm 9.3\,yr$$

$$A = 658 \pm 206\,s$$

$$c^2(d.o.f.) = 63.7(22)$$

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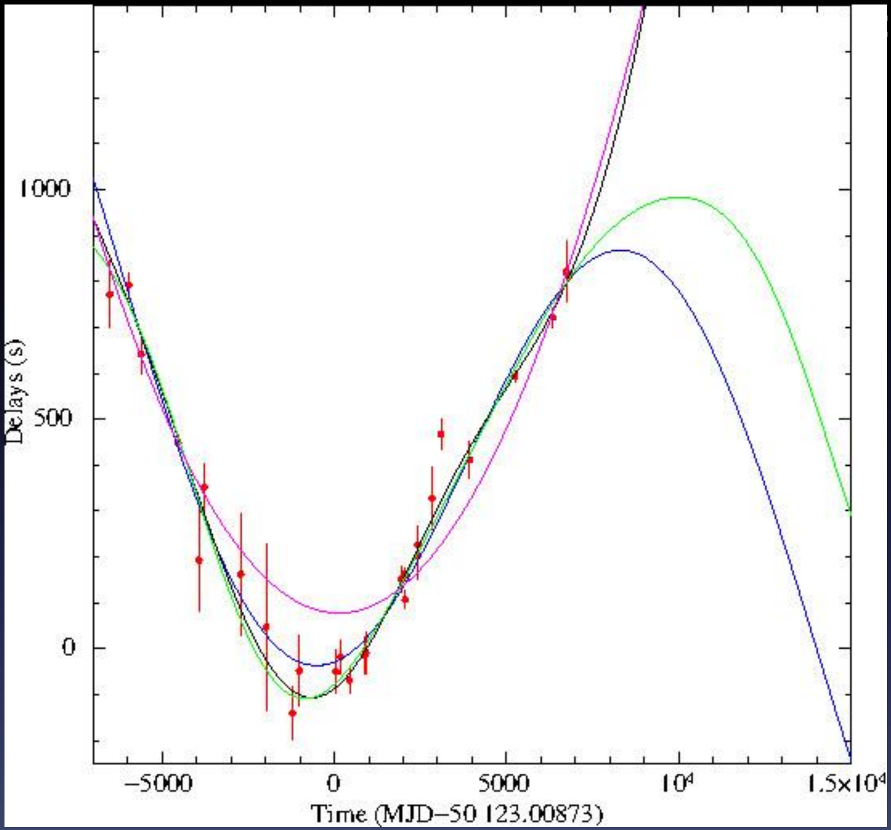
# Fitting the delays vs. time: the LINEAR+QUADRATIC+SINUSOIDAL (LQS) it




Remember that in our analysis the trial epoch of reference $T_0$ and the trial period $P_0$ are those of the orbital ephemeris shown by Hu, Chou & Chung (2008)

We fitted the data with a LINEAR+QUADRATIC+SINUSOIDAL (LQS) function (BLACK curve in the plot)

$$y(t) = a + bt + ct^2 + A\sin[\frac{2p}{P_{\mathrm{mod}}}(t - t_j)]$$

$$c^2(d.o.f.) = 39.4(21)$$

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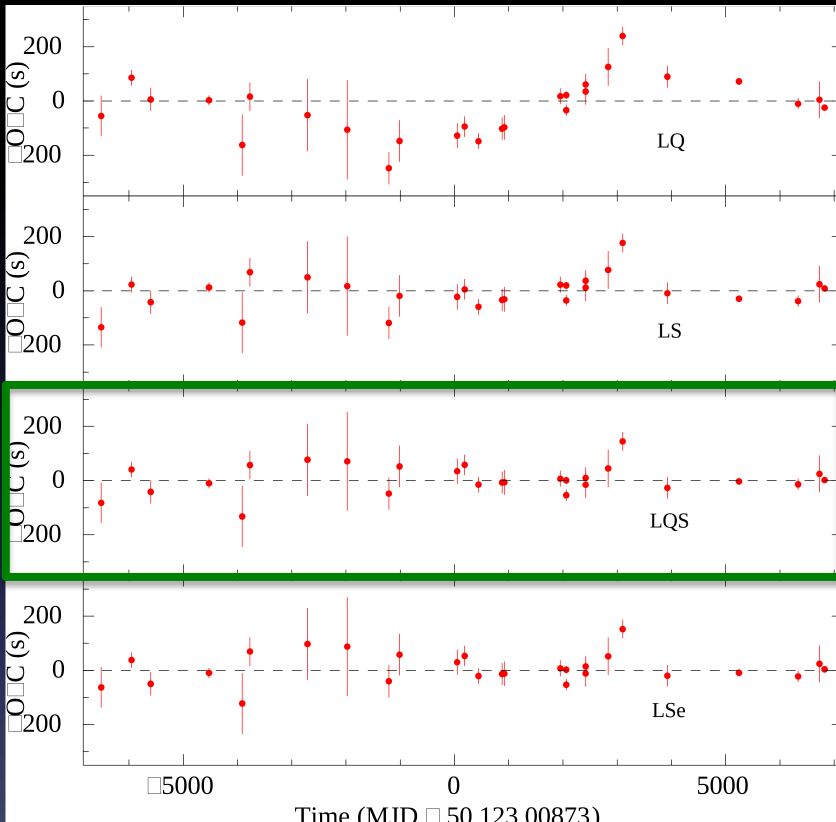
# Fitting the delays vs. time: the LINEAR+QUADRATIC+SINUSOIDAL (LQS) fit




Remember that in our analysis the trial epoch of reference $T_0$ and the trial period $P_0$ are those of the orbital ephemeris shown by Hu, Chou & Chung (2008)

$$T_0 = 50123.0089(3)\,MJD$$

$$P_0 = 3000.65126(10)\,s$$

$$\dot{P} = 1.44(7)\times 10^{-11}\,s/s$$

$$P_{mod} = 25.5 \pm 2.1\,yr$$

$$A = 130 \pm 15\,s$$

$$c^2(d.o.f.) = 39.4(21)$$

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# Preliminary discussion

| | *LS ephemeris* | *LQS ephemeris* |
|---|---|---|
| $T_0(MJD)$ | 50123.01549(18) | 50123.0089(3) |
| $P_0(s)$ | 3000.6496(8) | 3000.65126(10) |
| $\dot{P}(s/s)$ | **TOO LARGE!** → | $1.44(7)\times10^{-11}$ |
| $P_{\mathrm{mod}}(yr)$ | $55.9\pm9.3$ | $25.5\pm2.1$ |
| $A(s)$ | $658\pm206$ | $130\pm15$ |

The orbital period derivative is compatible with that shown bu Hu et al. (2008) [1.5(3) x $10^{-11}$ s/s].
"The standard model, in which mass loss and orbital period changes are due to gravitational radiation, predicts a positive orbital period derivative for LMXBs with degenerate companions. Using the Rappaport et al. model the orbital period derivative would be a factor of $10^2$-$10^3$ smaller than the observed value." (Hu et al., 2008)



# Preliminary discussion

| | $LS\ ephemeris$ | $LQS\ ephemeris$ |
|---|---|---|
| $T_0(MJD)$ | $50123.01549(18)$ | $50123.0089(3)$ |
| $P_0(s)$ | $3000.6496(8)$ | $3000.65126(10)$ |
| $\dot{P}(s/s)$ | **TOO LARGE!** → | $1.44(7)\times10^{-11}$ |
| $P_{mod}(yr)$ | $55.9\pm9.3$ | $25.5\pm2.1$ |
| $A(s)$ | $658\pm206$ | $130\pm15$ |

X 1/2

A further suspicion on the LQS ephemeris is the value of $P_{mod}$ that is almost a factor of 0.5 smaller then the $P_{mod}$ value associated with the LS ephemeris.



# Preliminary discussion

| | LS ephemeris | LQS ephemeris |
|---|---|---|
| $T_0(MJD)$ | 50123.01549(18) | 50123.0089(3) |
| $P_0(s)$ | 3000.6496(8) | 3000.65126(10) |
| $\dot{P}(s/s)$ | **TOO LARGE!** → | $1.44(7)\times10^{-11}$ |
| $P_{\text{mod}}(yr)$ | $55.9\pm9.3$ | $25.5\pm2.1$ |
| $A(s)$ | $658\pm206$ | $130\pm15$ |

X 1/2

If is LQS ephemeris trying to suggest an other possible orbital solution?

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# LSe Ephemeris

- Assuming that XB 1916-053 is part of hierarchical triple system the delays are affected by the the presence of a third body (as in the LS ephemeris)
- Assuming that the third body has an eccentric orbit

THEN the best function to fit the delays is:

$$y(t) = a + bt + D_{DS}(t)$$

$$D_{DS}(t) = A\{\sin(m_t + \nu) + \frac{e}{2}[\sin(2m_t + \nu) - 3\sin\nu] +$$
$$+\frac{e^2}{4}[2\sin(3m_t + \nu) - \sin(m_t + \nu)\cos(2m_t + 1) +$$
$$- 2\sin m_t \cos\nu]\}$$

$$m_t = \frac{2p}{P_{\mathrm{mod}}}(t - t_j)$$

(van der Klis & Bonnet-Bidaud; 1984)

We improved the function $\Delta_{DS}(t)$ wrt vdKBB introducing the term in $e^2$. In the expression:

- e is the eccentricity of the orbit
- $m_t$ is the mean anomaly
- ω is the periastron angle
- $P_{mod}$ is the orbital period of the third body around the binary system
- $t_\varphi$ is the passage time at the periastron

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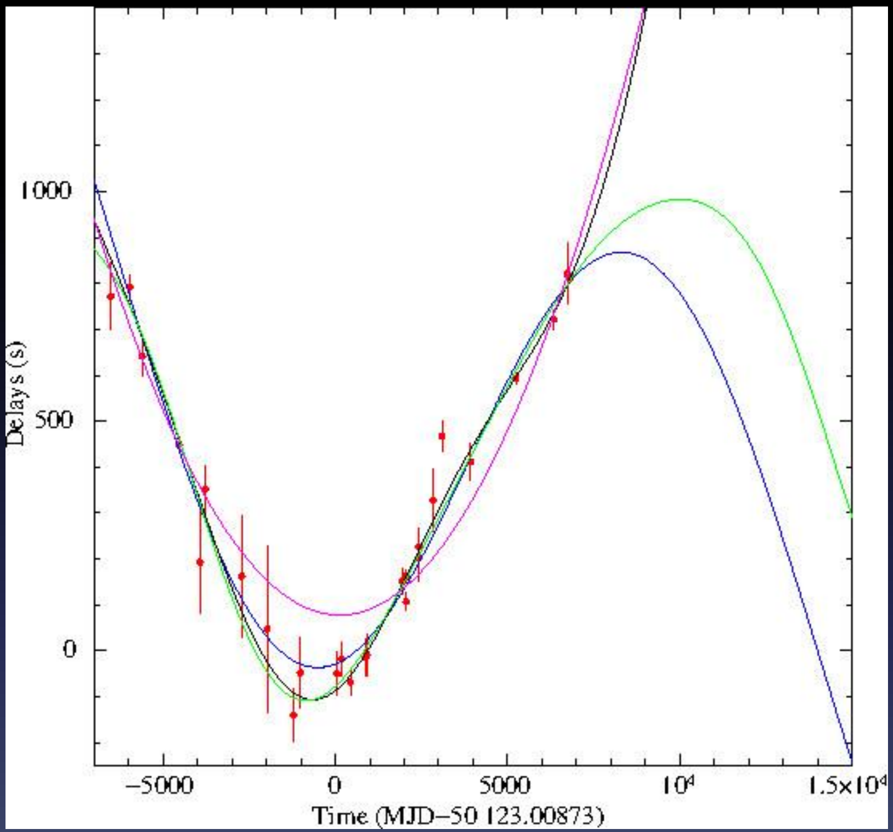
# Fitting the delays vs. time: the LSe fit




Remember that in our analysis the trial epoch of reference $T_0$ and the trial period $P_0$ are those of the orbital ephemeris shown by Hu, Chou & Chung (2008)

We fitted the data with a LSe function (GREEN curve in the plot)

$$y(t) = a + bt + D_{DS}(t)$$

$$c^2(d.o.f.) = 48.2(21)$$

Unfortunately the function is over parameterised and we are not able to estimate the error associated with $P_{mod}$.

We fixed $P_{mod}$ to its best-fit value of 50.9 yr

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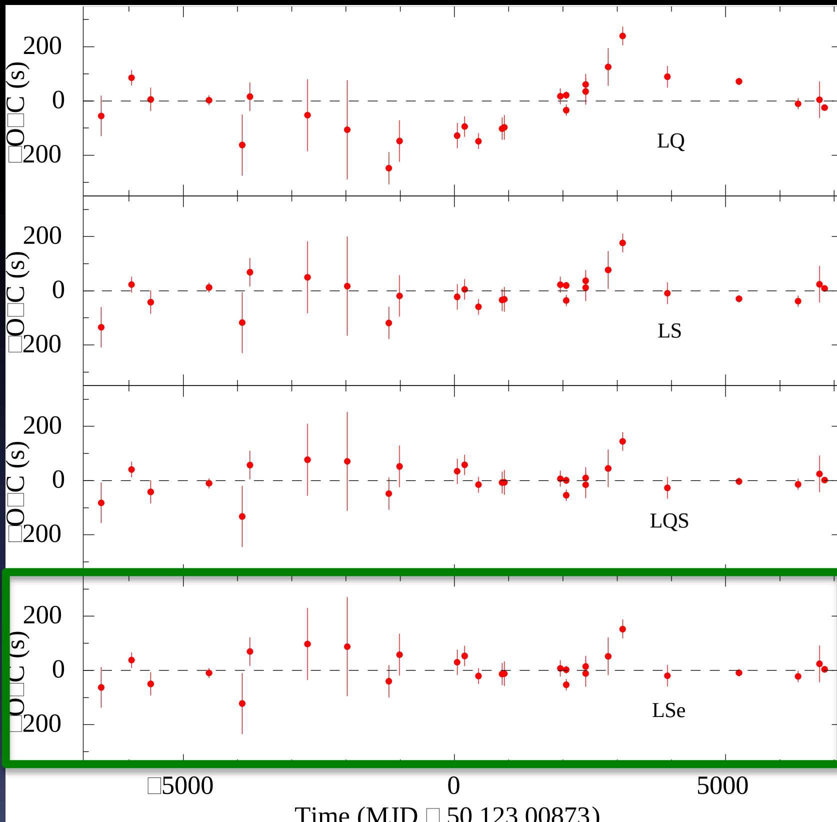
# Fitting the delays vs. time: the LSe fit




Remember that in our analysis the trial epoch of reference $T_0$ and the trial period $P_0$ are those of the orbital ephemeris shown by Hu, Chou & Chung (2008)

$$T_0 = 50123.010(3)\ MJD$$

$$P_0 = 3000.6512(6)\ s$$

$$P_{mod} \simeq 50.9\ yr$$

$$A = 548 \pm 43\ s$$

$$e = 0.28 \pm 0.15$$

$$\nu = 210 \pm 28\,\mathrm{deg}$$

$$\chi^2(d.o.f.) = 48.2(21)$$

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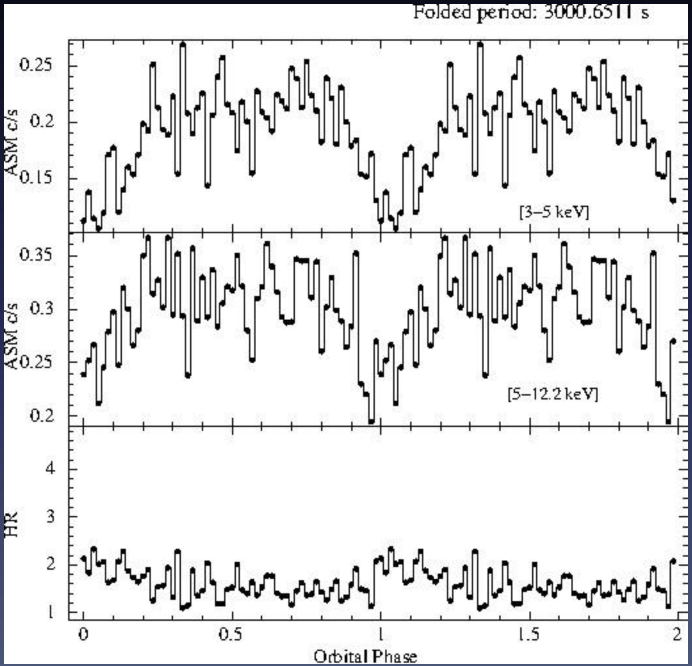
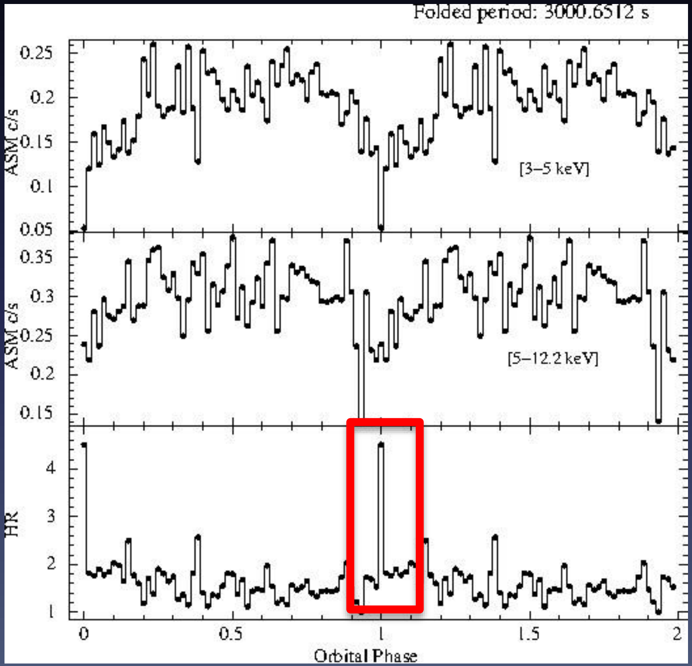
# Independent check folding the *RXTE*/ASM light curve: the LSe ephemeris

We folded the RXTE/ASM light curves in the 3-5 and 5-12.2 keV energy band.
The ASM light curve covers from 1996 Sep 01 to 2011 Oct 31.

If our ephemeris is correct we expect the hardness ratio should be larger at phase 0 because the larger photoelectric absorption during the dip.




Left: Hu's ephemeris

Right: our LSe ephemeris

The bin time is 50 s



# Discussion

The mass-radius relation of a He-dominated degenerate star is

$$\frac{R_2}{R_{sun}} = 0.0126 \; m_2^{-1/3} f$$

Where f is the thermal bloating factor and takes into account that the star is not only supported by the Fermi pressure (e.g. nuclear reactions in the core)

Since XB 1916-053 is a LMXB, the companion star fills its Roche Lobe.

Combining the Roche Lobe radius equation of the companion star with the third Kepler's law  and considering an orbital period of 3000.65 s, we obtain that the companion star mass is given by

$$m_2 = 0.0151 f^{3/2}$$



# Discussion: the conservative mass transfer scenario

The not-absorbed 0.1-100 keV luminosity is

$$L_x \simeq 5.2\times 10^{36}\, erg/s \quad M_{NS} = 1.4\ M_{sun}$$

$$L_x \simeq 6.6\times 10^{36}\, erg/s \quad M_{NS} = 2.2\ M_{sun}$$

Using the relation between luminosity and orbital period for highly compact X-ray binary system for a conservative mass-transfer scenario (Rappaport et al.; 1987)

$$L_x = 5.2\times 10^{42}\, m_{NS}^{5/3} P_m^{-14/3} f^3\, erg/s \rightarrow$$

$$f = 3.6 \pm 0.4 \quad M_{NS} = 1.4 M_{sun}$$

$$f = 3.0 \pm 0.3 \quad M_{NS} = 2.2 M_{sun}$$

$$\rightarrow m_2 = 0.0151 f^{3/2}$$

$$M_2 = 0.10 \pm 0.02\ M_{sun} \rightarrow M_{NS} = 1.4 M_{sun}$$

$$M_2 = 0.078 \pm 0.012\ M_{sun} \rightarrow M_{NS} = 2.2 M_{sun}$$

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# Discussion: the conservative mass transfer scenario

Using the relation between orbital period derivative and orbital period for highly compact X-ray binary system for a conservative mass-transfer scenario (Rappaport et al.; 1987)

$$\dot{P} = 1.54 \times 10^{-9} m_{NS}^{2/3} P_m^{-8/3} f^{3/2} s/s$$

↓

$$\dot{P} = (3.9 \pm 0.2) \times 10^{-13} s/s \rightarrow M_{NS} = 1.4 M_{sun}$$

$$\dot{P} = (3.98 \pm 0.15) \times 10^{-13} s/s \rightarrow M_{NS} = 2.2 M_{sun}$$

The orbital period derivative is a factor of 40 smaller than that predicted by LQS ephemeris and weakly depends on the neutron star mass.



# Discussion: the conservative mass transfer scenario

We fitted again the delays vs. time using the LSe function and taking into account an orbital period derivative of $3.9\times10^{-13}$ s/s.
The orbital solution is unchanged.

$$T_0 = 50123.010(3)\ MJD$$
$$P_0 = 3000.6512(6)\ s$$
$$\dot{P} = (3.9 \pm 0.2) \times 10^{-13}\ s/s$$
$$P_{\rm mod} \equiv 50.9\ \ yr$$
$$A = 534 \pm 43\ \ s$$
$$e = 0.28 \pm 0.15$$
$$\varpi = 213 \pm 28 \deg$$

We added a quadratic term to the LSe ephemeris where c = 5 $10^{-7}$ s $d^{-2}$ corresponds to an orbital period derivative of $3.9\times10^{-13}$ s/s.



# Discussion: the mass of the third body

The orbital solution of LSe ephemeris is self-consistent and suggest that the large change of the delays vs. time is due to the presence of a third body that alters the dip arrival times according to the Kepler's laws.

$$T_0 = 50123.010(3)\ \ MJD$$

$$P_0 = 3000.6512(6)\ \ s$$

$$\dot{P} = (3.9 \pm 0.2) \times 10^{-13}\, s/s$$

$$P_{\mathrm{mod}} \equiv 50.9\ \ yr$$

$$A = 534 \pm 43\ \ s$$

$$e = 0.28 \pm 0.15$$

$$\varpi = 213 \pm 28 \deg$$

The distance of the centre of mass (CM) of the X-ray binary system from the CM of the triple system is

$$a_x = a_{bin} \sin i = Ac = (1.60 \pm 0.13) \times 10^{13}\, cm$$

Where i is the inclination angle of the system. It is between 60° and 80°. We assume i=70°.



# Discussion: the mass of the third body

The orbital solution of LSe ephemeris is self-consistent and suggest that the large excursion of the delays vs. time is due to the presence of a third Body that alters the dip arrival times according to the Kepler's laws.

$$T_0 = 50123.010(3)\ \ MJD$$
$$P_0 = 3000.6512(6)\ \ s$$
$$\dot{P} = (3.9 \pm 0.2) \times 10^{-13}\, s/s$$
$$P_{\text{mod}} \equiv 50.9\ \ yr$$
$$A = 534 \pm 43\ \ s$$
$$e = 0.28 \pm 0.15$$
$$\varpi = 213 \pm 28\,\text{deg}$$

Using the Mass function relation:

$$\frac{M_3 \sin i}{(M_3 + M_{bin})^{2/3}} = \left(\frac{4\pi^2}{G}\right)^{1/3} \frac{a_x}{P_{\text{mod}}^{2/3}}$$

We find

$$M_3 = (0.108 \pm 0.010)\ M_{sun} \rightarrow M_{NS} = 1.4 M_{sun}$$
$$M_3 = (0.143 \pm 0.012)\ M_{sun} \rightarrow M_{NS} = 2.2 M_{sun}$$

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# Conclusions

The study of the dip arrival times allows us to predict that XB 1916-053 is part of a hierarchical triple system. For a conservative mass transfer scenario:

$$T_0 = 50123.010(3)\ MJD$$

$$P_0 = 3000.6512(6)\ s$$

$$\dot{P} = (3.9 \pm 0.2) \times 10^{-13}\ s/s$$

$$P_{\mathrm{mod}} \equiv 50.9\ \ yr$$

$$A = 534 \pm 43\ \ s$$

$$e = 0.28 \pm 0.15$$

$$\varpi = 213 \pm 28\,\mathrm{deg}$$

$$M_2 = 0.10 \pm 0.02\ \ M_{sun} \rightarrow M_{NS} = 1.4 M_{sun}$$

$$M_2 = 0.078 \pm 0.012\ \ M_{sun} \rightarrow M_{NS} = 2.2 M_{sun}$$

$$M_3 = (0.108 \pm 0.010)\ \ M_{sun} \rightarrow M_{NS} = 1.4 M_{sun}$$

$$M_3 = (0.143 \pm 0.012)\ \ M_{sun} \rightarrow M_{NS} = 2.2 M_{sun}$$



# Thanks for your attention
# and
# merry Xmas

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# What we know on XB 1916-053

The periodic recurrence of the dips in the light curve allows to obtain a rough estimation of the orbital period from pointing observations  covering more than one orbital cycle.

- $P_{orb}$ = 3003.6 ± 1.8 s    *Einstein* data  (White & Swank, 1982)
- $P_{orb}$ = 3005.0 ± 6.6 s    *GINGA*  data  (Smale et al., 1989)
- $P_{orb}$ = 3005 ± 10 s    *ASCA*    data  (Church et al., 1997)

The orbital period is roughly 50 min

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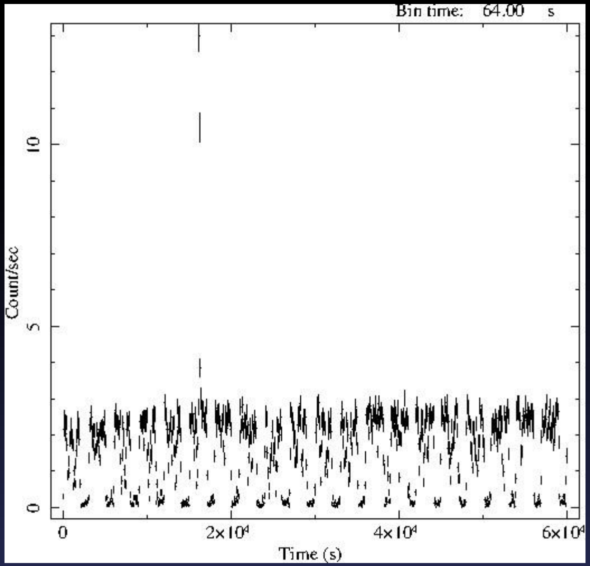
# Our Dataset

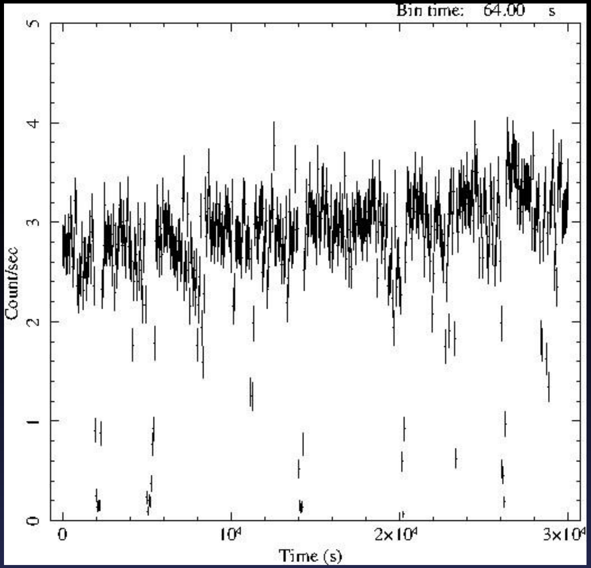
| Point | Satellite/Instrument | Observation | Start Time (UT) | Stop Time (UT) | $T_{fold}$ (MJD TDB) |
|---|---|---|---|---|---|
| 1 | OSO-8/GCXSE | | 1978 Apr 07 21:16:05 | 1978 Apr 14 22:20:37 | 43 609.408575724435 |
| 2 | Einstein/IPC | | 1979 Oct 22 04:52:01 | 1979 Oct 22 06:58:30 | 44 168.24670380917 |
| 3 | Einstein/IPC | | 1980 Oct 11 04:08:51 | 1980 Oct 11 09:07:19 | 44 523.27644368849 |
| 4 | EXOSAT/ME | | 1983 Sep 17 15:07:25 | 1983 Sep 17 21:29:49 | 45 594.765324269885 |
| 5 | EXOSAT/ME | | 1985 May 24 12:26:21 | 1985 May 24 21:30:23 | 46 209.612747685185 |
| 6 | EXOSAT/ME | | 1985 Oct 13 13:53:16 | 1985 Oct 13 22:34:04 | 46 351.75944524423 |
| 7 | Ginga/LAC | | 1988 Sep 09 15:47:56 | 1988 Sep 10 16:01:16 | 47 414.165911835925 |
| 8 | Ginga/LAC | | 1990 Sep 11 15:04:35 | 1990 Sep 13 09:18:11 | 48 146.51075733274 |
| 9 | ROSAT/PSPC | RP400274N00 | 1992 Oct 17 13:05:47 | 1992 Oct 19 15:24:20 | 48 913.59379352164 |
| 10 | ASCA/GIS3 | 40004000 | 1993 May 02 18:11:00 | 1993 May 03 09:46:17 | 49 110.082393510115 |
| 11 | RXTE/PCA | P10109-01-01-00, P10109-01-02-00, P10109-01-04-01, P10109-01-04-00, P10109-02-01-00, P10109-02-02-00, P10109-02-03-00, P10109-02-04-00, P10109-02-05-00, P10109-02-06-00, P10109-02-07-00,P10109-02-08-00, P10109-02-09-00, P10109-02-10-00, P10109-02-10-02 | 1996 Feb 02 00:14:56 | 1996 May 23 11:20:00 | 50 174.74129123185 |
| 12 | RXTE/PCA | P10109-01-05-00, P10109-01-06-00, P10109-01-07-00, P10109-01-08-00, P10109-01-09-00 | 1996 Jun 01 17:38:40 | 1996 Oct 29 11:00:34 | 50 310.596956288645 |
| 13 | BeppoSAX/MECS | 20106001 | 1997 Apr 27 21:00:06 | 1997 Apr 28 19:51:02 | 50 566.35264963594 |
| 14 | RXTE/PCA | P30066-01-01-04, P30066-01-01-00, P30066-01-01-01, P30066-01-01-02, P30066-01-01-03, P30066-01-02-00, P30066-01-02-01, P30066-01-02-02, P30066-01-02-03 | 1998 Jun 23 23:06:40 | 1998 Jul 20 15:35:55 | 51 001.306447481845 |
| 15 | RXTE/PCA | P30066-01-02-04, P30066-01-02-07, P30066-01-02-08, P30066-01-03-00, P30066-01-03-01, P30066-01-03-02, P30066-01-03-03, P30066-01-03-04, P30066-01-03-05, P30066-01-04-00 | 1998 Jul 21 07:11:44 | 1998 Sep 16 02:52:32 | 51 043.70980975036 |
| 16 | RXTE/PCA | P30066-01-05-01, P30066-01-05-00, P30066-01-06-00, P30066-01-06-01, P30066-01-07-00, P30066-01-07-01 | 2001 May 27 08:14:47 | 2001 Jul 01 19:15:33 | 52 074.07302734295 |
| 17 | BeppoSAX/MECS | 21373002 | 2001 Oct 01 03:40:16 | 2001 Oct 02 07:01:06 | 52 183.72270184033 |
| 18 | RXTE/PCA | P50026-03-01-00, P50026-03-01-01 | 2001 Oct 01 10:35:44 | 2001 Oct 01 22:16:03 | 52 183.684644754605 |
| 19 | RXTE/PCA | P70034-02-02-01, P70034-02-02-00 | 2002 Sep 25 00:43:12 | 2002 Sep 25 09:31:12 | 52 542.21332826887 |
| 20 | XMM/Epic-pn | 0085290301 | 2002 Sep 25 04:18:29 | 2002 Sep 25 08:28:27 | 52 542.266295747205 |
| 21 | INTEGRAL/JEM-X | | 2003 Nov 09 09:04:11 | 2003 Nov 20 12:18:01 | 52 957.945226848465 |
| 22 | Chandra/HETGS | 4584 | 2004 Aug 07 02:34:45 | 2004 Aug 07 16:14:53 | 53 224.59478392645 |
| 23 | Suzaku/XIS0 | 401095010 | 2006 Nov 08 06:09:51 | 2006 Nov 09 02:42:02 | 54048.3655207864 |
| 24 | RXTE/PCA | P95093-01-01-00, P95093-01-01-01 | 2010 Jun 19 13:41:52 | 2010 Jun 21 07:21:46 | 55 367.43875650959 |
| 25 | Chandra/LETGS | 15271, 15657 | 2013 Jun 15 13:56:17 | 2013 Jun 18 05:13:17 | 56 459.89915961875 |
| 26 | Swift/XRT | 00033336001 | 2014 Jul 15 08:04:57 | 2014 Jul 15 22:36:46 | 56853.63959388178 |
| 27 | Suzaku/XIS0 | 409032010, 409032020 | 2014 Oct 14 16:49:56 | 2014 Oct 22 2:40:56 | 56 949.56345974802 |



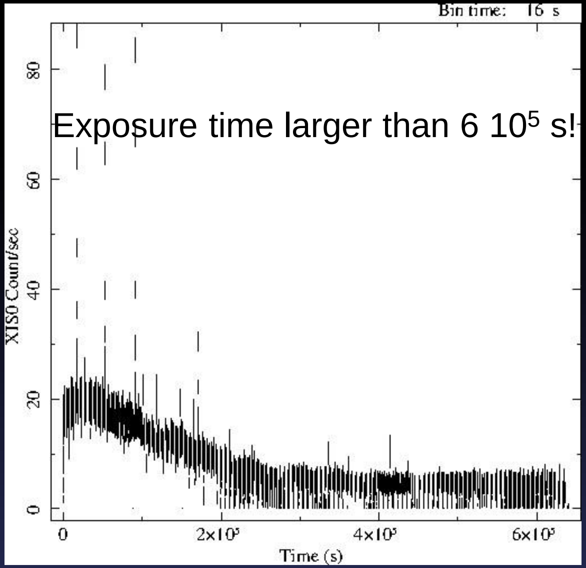
# The Chandra/LEG and Suzaku/XIS0 light curves




Chandra/LEG Obsid. 15271




Chandra/LEG Obsid. 15271




Suzaku/XIS0
Obsid.409032010

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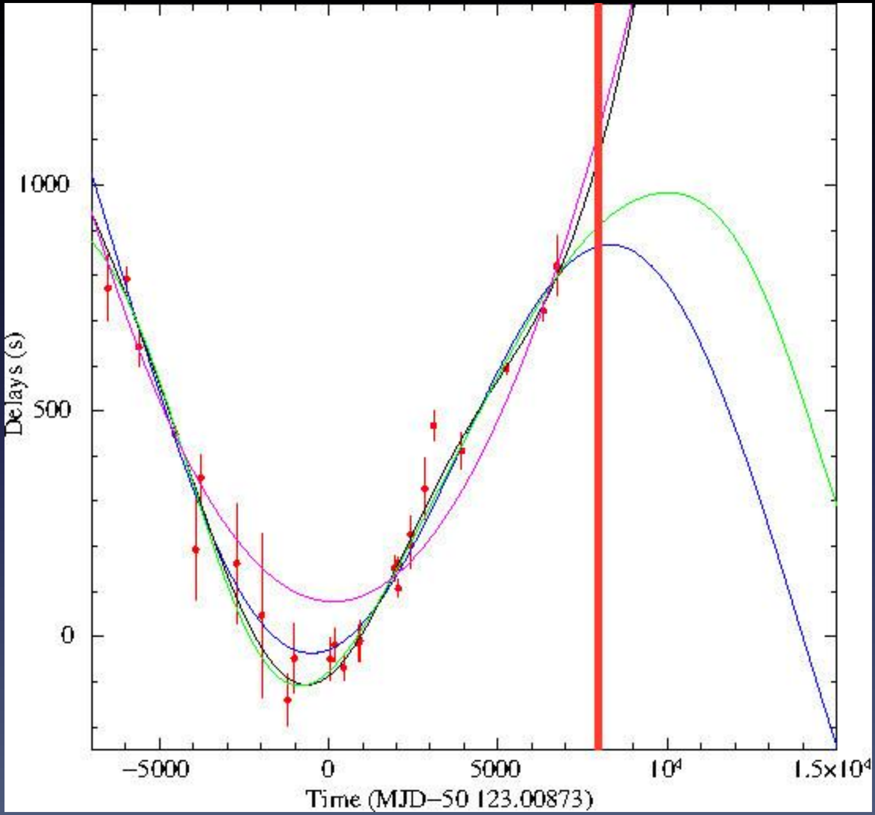
# Prediction

The vertical line indicates the date 2018 Jan 5. An observation taken after this date will allow to discriminate between LQS and Lse ephemeris

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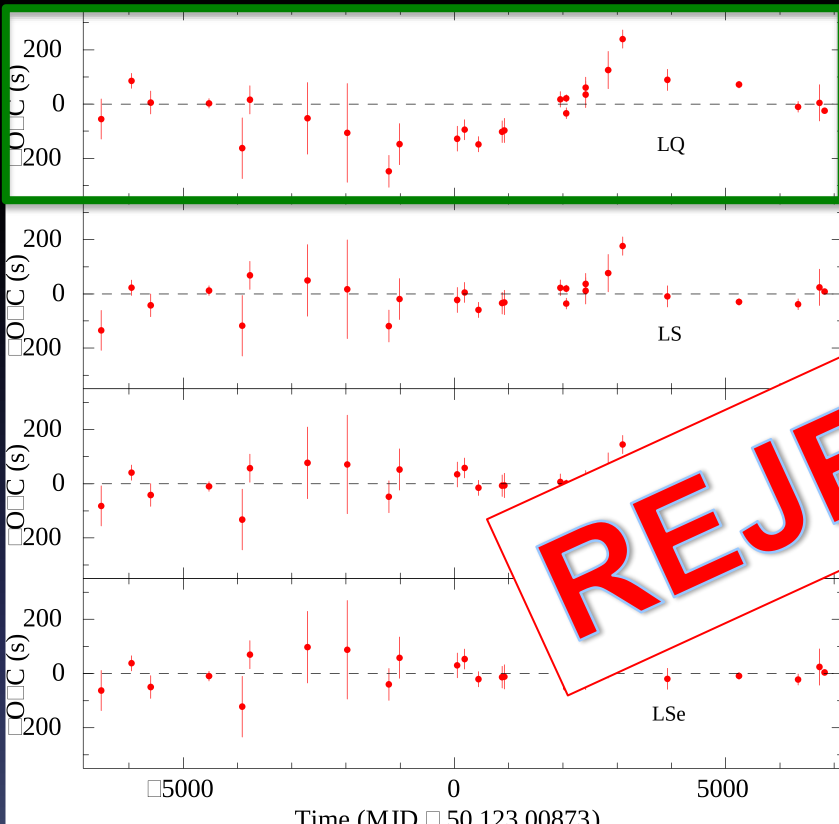
R. Iaria,Texas Symposium 2015, Genève (Suisse), 15 Dec 2015

# Fitting the delays vs. time: the PARABOLIC (LQ) fit




Remember that in our analysis the trial epoch of reference $T_0$ and the trial period $P_0$ are those of the orbital ephemeris shown by Hu, Chou & C[illegible]ng (2008)

REJECTED

$$(t) = a + bt + ct^2$$

Where:

$$a = \Delta T_0$$

$$b = \Delta P / P_0$$

$$c = \tfrac{1}{2} \dot{P} / P_0$$

$$c^2 (d.o.f.) = 194.6(24)$$

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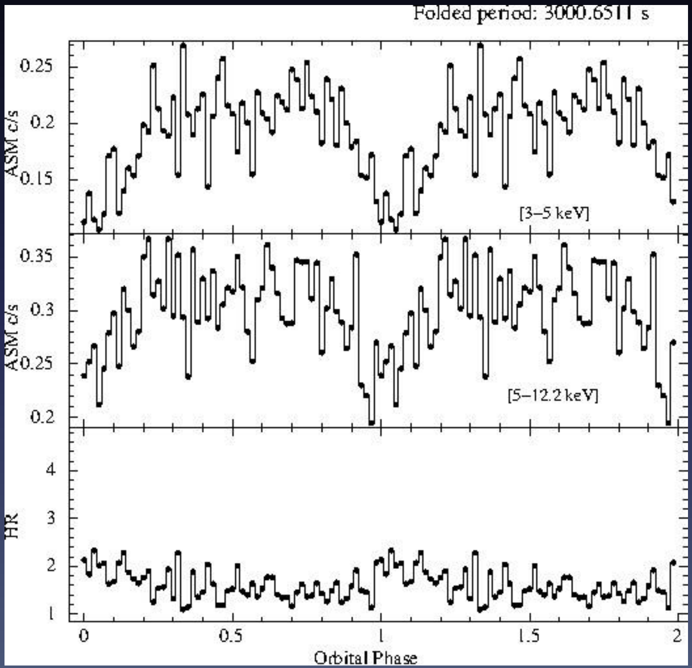
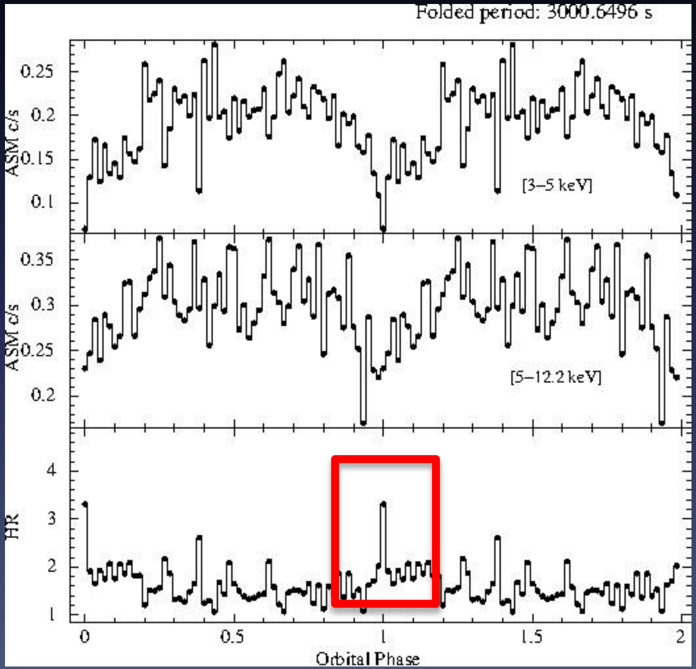
# Independent check folding the *RXTE*/ASM light curve: the LS ephemeris

We folded the RXTE/ASM light curves in the 3-5 and 5-12.2 keV energy band.
The ASM light curve covers from 1996 Sep 01 to 2011 Oct 31.

If our ephemeris is correct we expect the hardness ratio should be larger at phase 0 because the larger photoelectric absorption during the dip.




Left: Hu's ephemeris

Right: our LS ephemeris

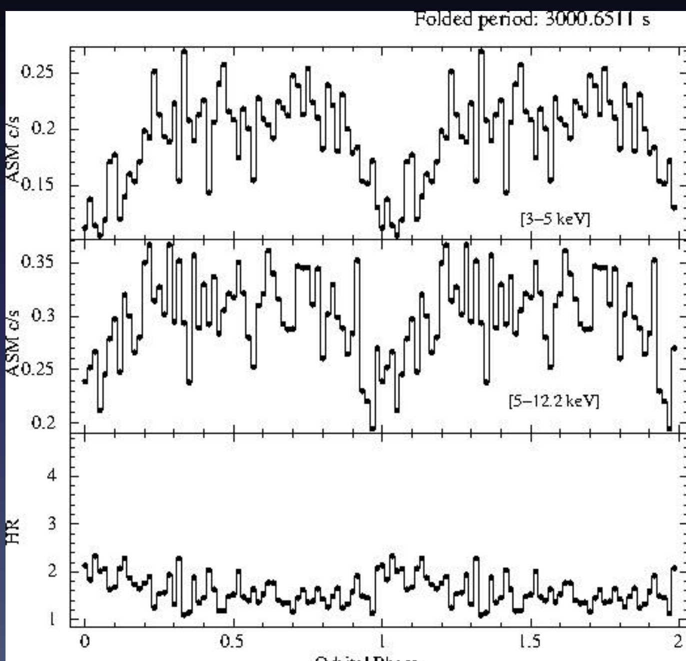
The bin time is 50 s

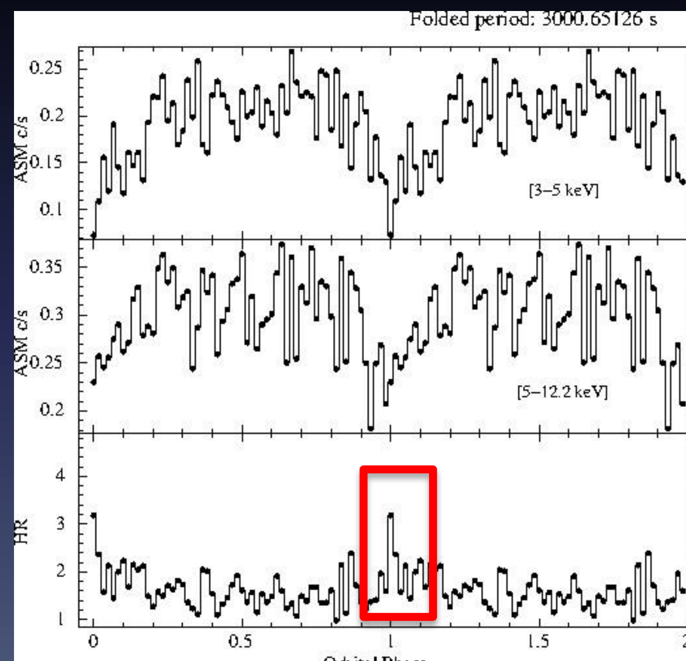


# Independent check folding the *RXTE*/ASM light curve: the LQS ephemeris

We folded the RXTE/ASM light curves in the 3-5 and 5-12.2 keV energy band.
The ASM light curve covers from 1996 Sep 01 to 2011 Oct 31.

If our ephemeris is correct we expect the hardness ratio should be larger at phase 0 because the larger photoelectric absorption during the dip.




Left: Hu's ephemeris

Right: our LQS ephemeris

The bin time is 50 s