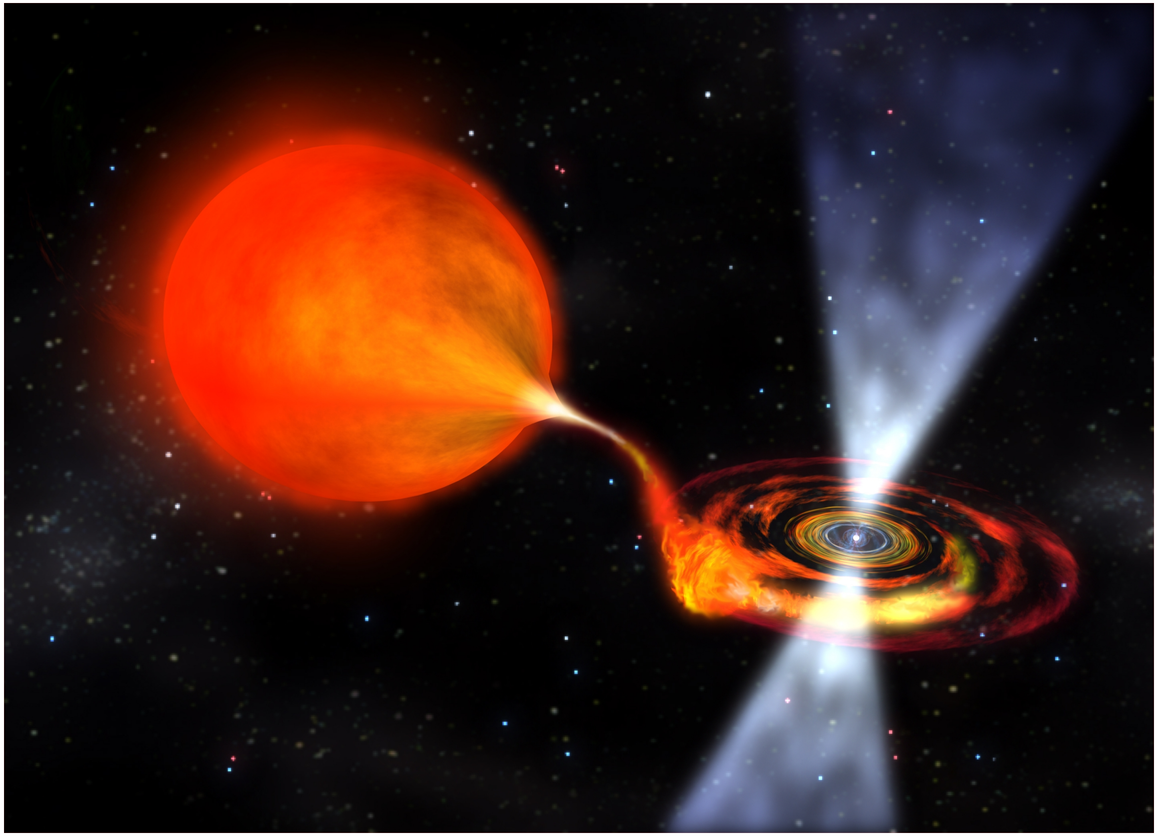
Enlightening Differences in Accreting Millisecond Pulsars behavior



Alessandro Papitto

UNIVERSITA' DEGLI STUDI DI ROMA Tor Vergata

OAR

In collaboration with:
Luciano Burderi (Univ. Cagliari)
Tiziana Di Salvo (Univ. Palermo)
Alessandro Riggio (Univ.Cagliari)
Maria Teresa Menna (INAF OAR)

thanks to... esa Education

The X-ray Universe 2008
Granada – 27 / 30 May

Plan

- Accreting Millisecond Pulsars
- Results from timing techniques
  - Rotational behavior during accretion phases (spin up & spin down)
  - Geometrical model to explain Phase Movements
  - The non conservative orbital evolution of SAXJ1808.8-3658
- Future Prospects (XMM-Newton)

AmsP: basic facts

	P_{spin} (ms)	Porb (hr)	
• SAX J1808.4-3658	2.5	2.01	Wijnands & van der Klis 1998
• XTE J1751-305	2.3	0.70	Markwardt et al. 2002
• XTE J0929-314	5.4	0.73	Galloway et al. 2002
• XTE J1807-294	5.2	0.67	Markwardt et al. 2003
• XTE J1814-338	3.2	4.27	Markwardt et al. 2003
• IGR J00291+5934	1.7	2.46	Galloway et al. 2005
• **HETE J1900.1-2455**	2.7	1.39	Kaaret et al. 2005
• SWIFT J1756-2508	5.5	0.90	Markwardt et al. 2007
• **4U 1908+005 (Aql X-1)**	1.8	19.0	Casella et al. 2008
• **SAX J1748.9-2021**	2.3	8.7	Altamirano et al. 2008

All these sources are **transients,** relatively **faint** (0.01-0.1% L_{Edd})
and some show only **intermittent pulsations**

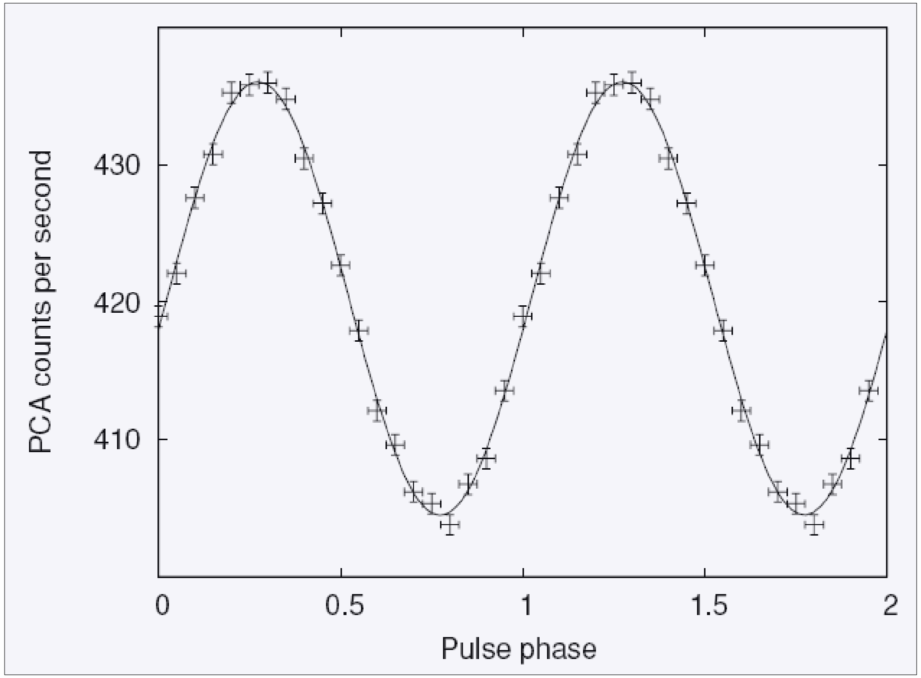
Role of timing analyses

- Catch the small spin period variations due to the torques acting on the NS
  - Material torque
  - Magnetic torque (magnetosphere – disc interaction)
  - GW quadrupole emission
  - Orbit and its evolution

- Model the pulse profile and trace the phase temporal evolution

- Technique limited by the outburst duration

(2 months at most – very short compared to RadioPSR)



XTE J1751-338

Spin Up during outburst

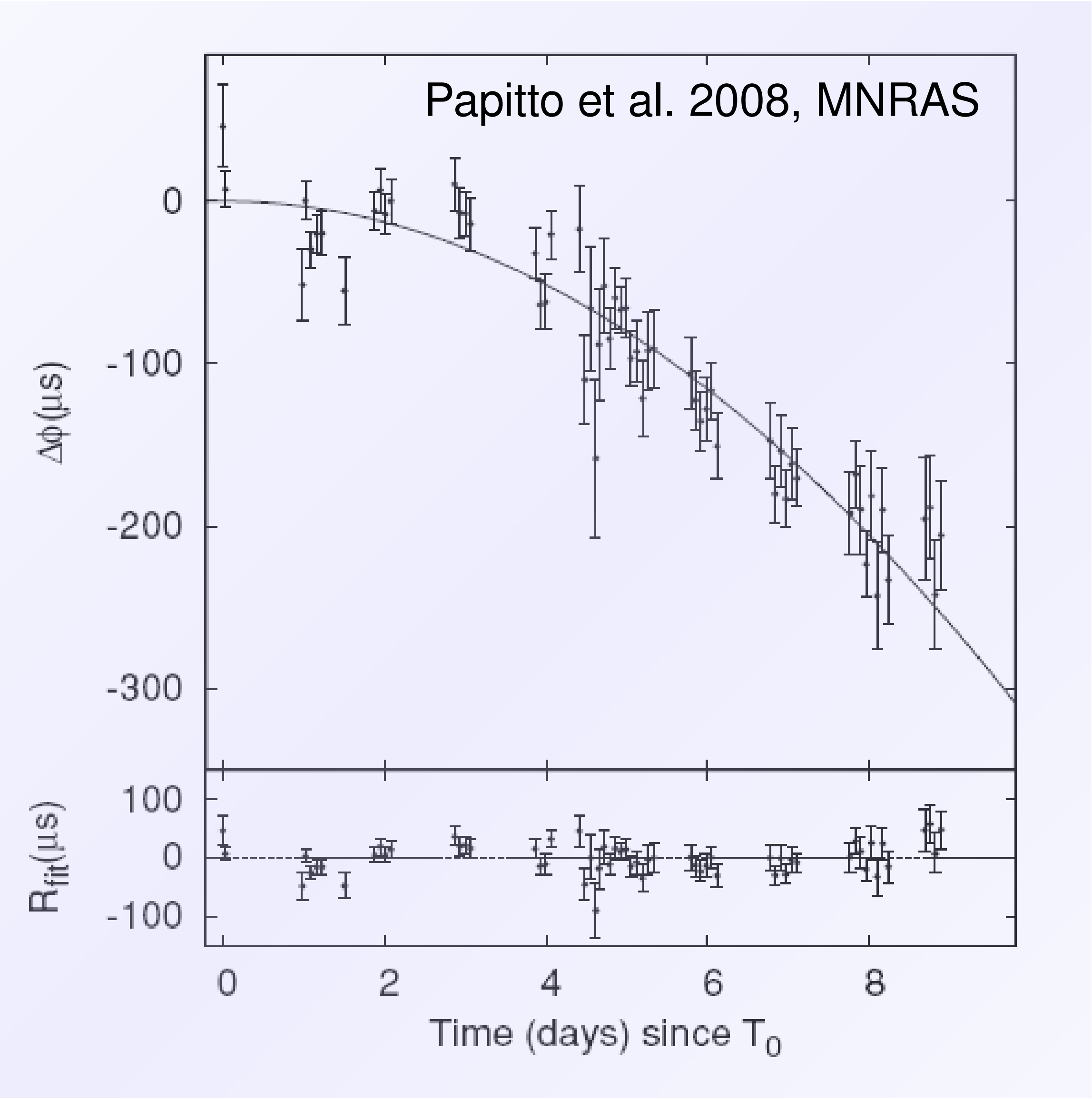
$<d\nu/dt> = (3.7 \pm 1.0) \times 10^{-13}$ Hz/s
The relative variation is of
6 parts on 10^{10} !!!

Instantaneous mass accretion rate:
$dM/dt^{peak} > 3 \times 10^{-9}\ M_{sun}/yr$

Distance
$D \cong 8.5$ kpc

Consistent with previous lower limits
from GW driven evolution

Similar results are also obtained for
the fastest spinning AMSP,
IGR J00291+5934



XTE J1814-338

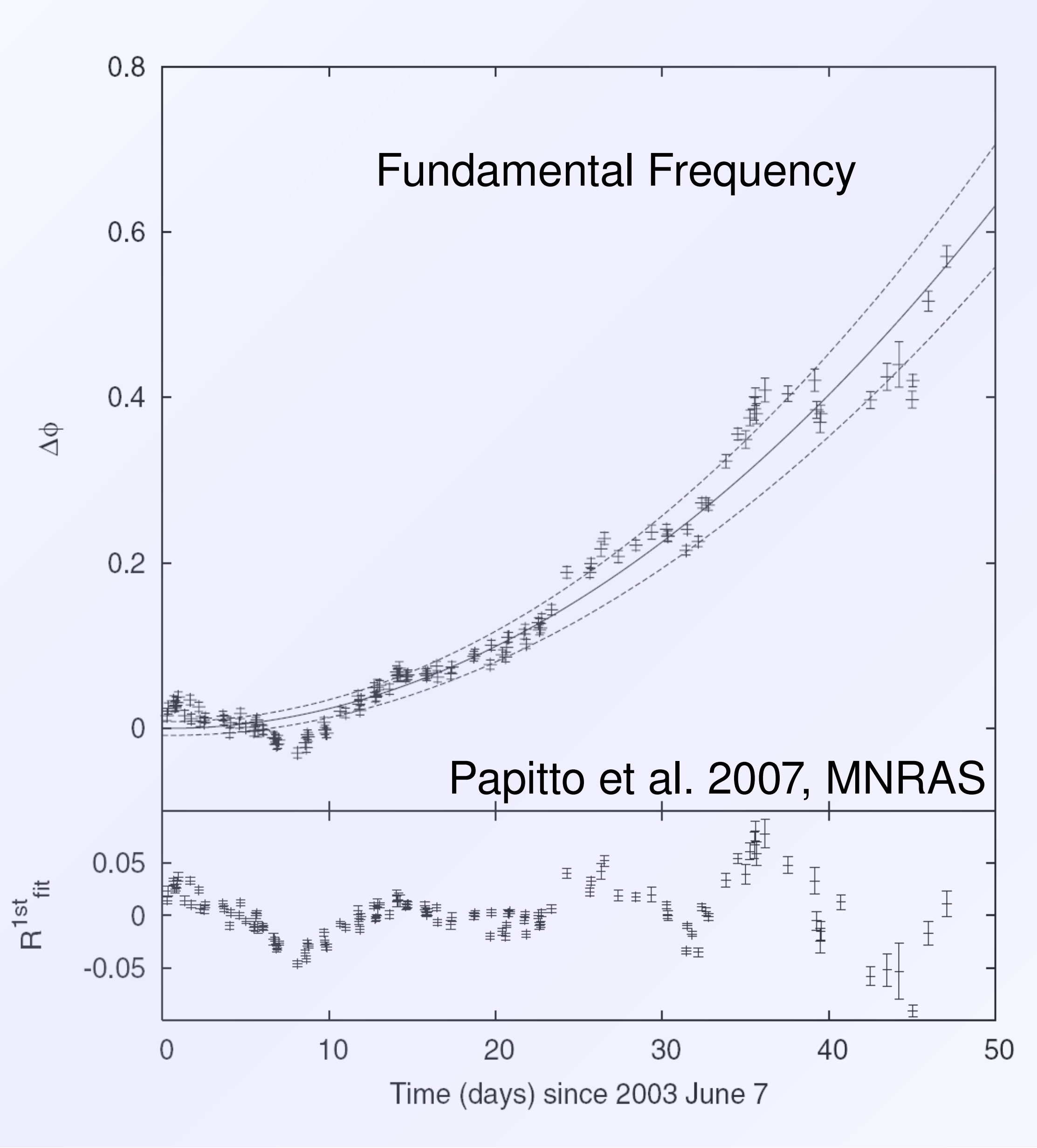
The opposite curvature evidences
SPIN DOWN

$\langle d\nu/dt \rangle = (-6.7 \pm 0.7) \times 10^{-14}$ Hz/s

Spin down in an accreting pulsar: interaction between the fast spinning magnetosphere and the accretion disc (e.g. Ghosh & Lamb 1979)

$B_S \approx 8 \times 10^8$ G

but 5σ oscillations around the mean trend, present in both the harmonics, have to be explained...



XTE J1814-338: phase oscillations

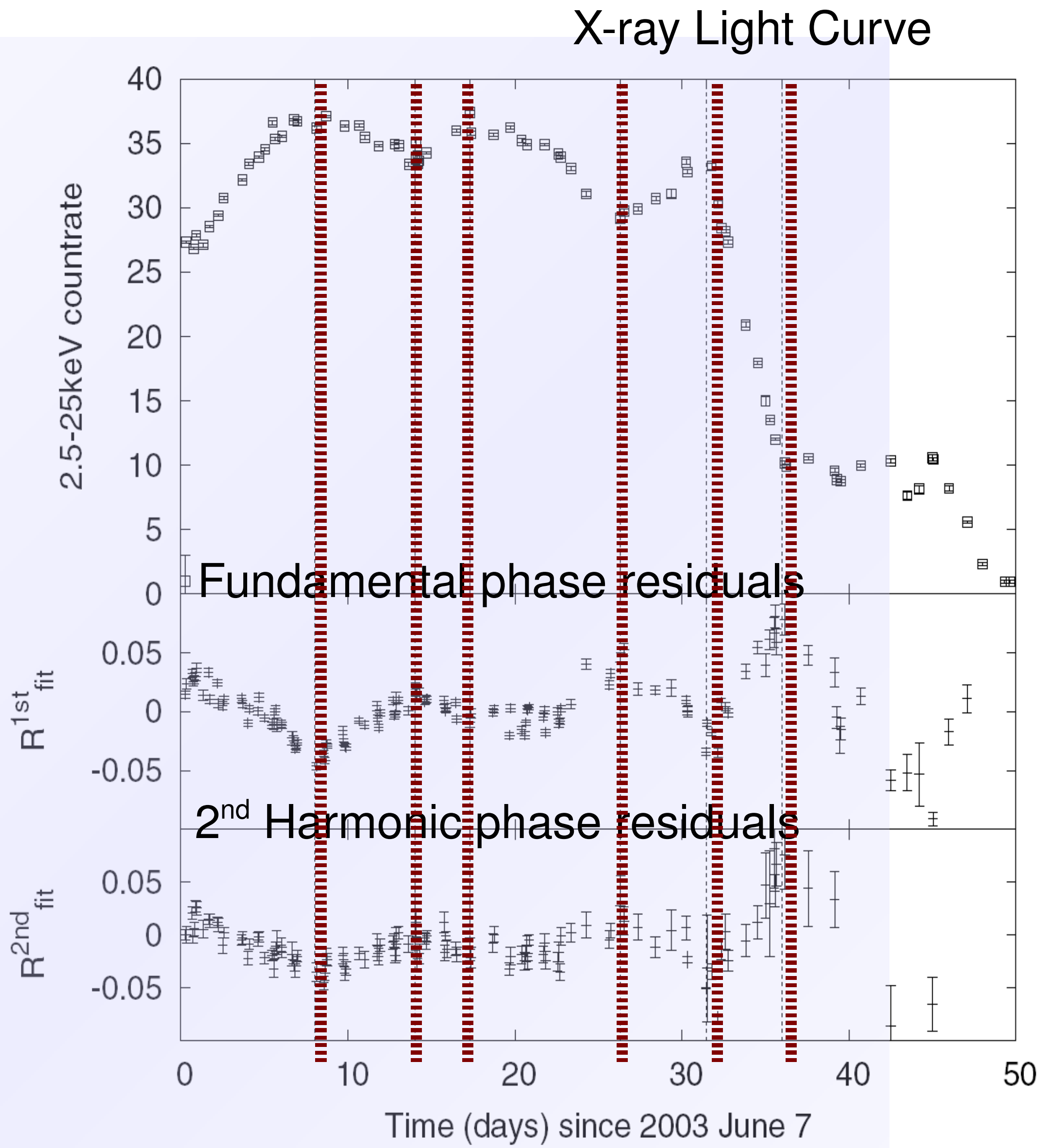
- Phases oscillate with amplitude ≈ 0.05 (20°) and timescale ≈ 12d

- Phase oscillations are clearly anti-correlated with X-ray flux variations

Viable explanations:

✓ Movements of the hot spot (but should be of > 40° in longitude)

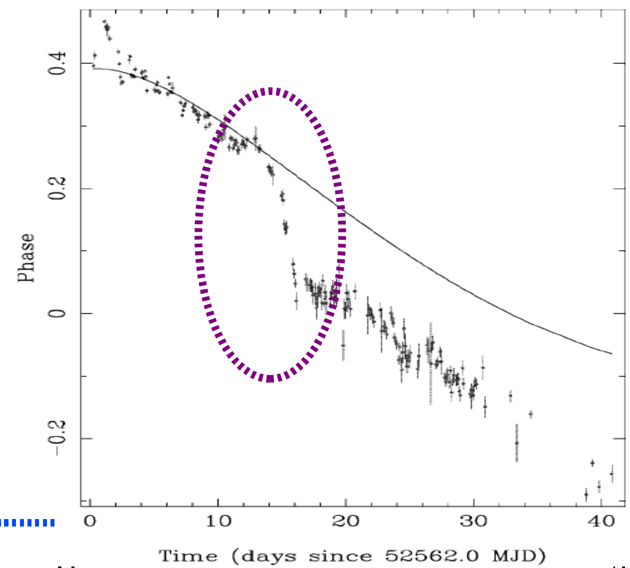
✓ Geometrical effects

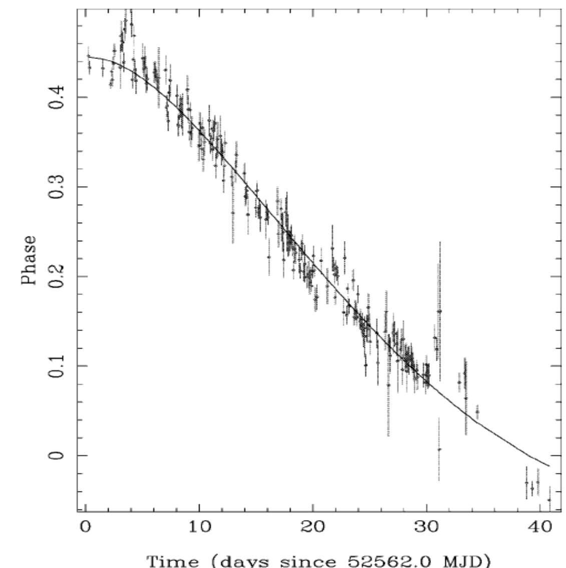


More phase oscillations

Fundamental Frequency

2^{nd} Harmonic





SAX J1808.4-3658

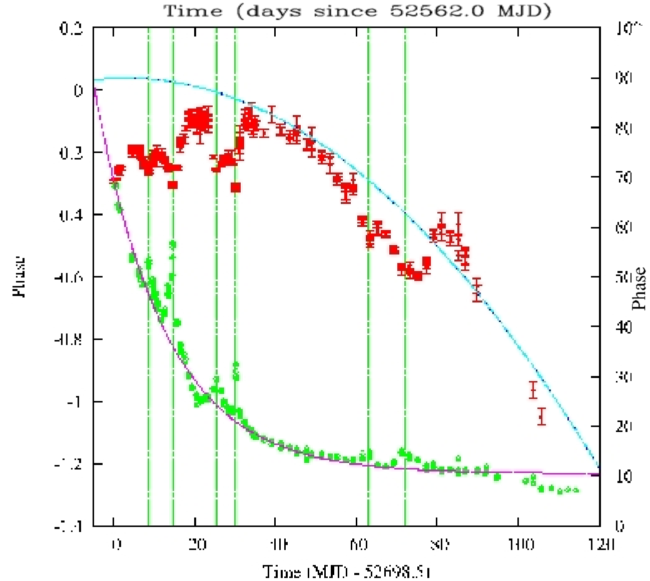
Phase jump only in the fundamental

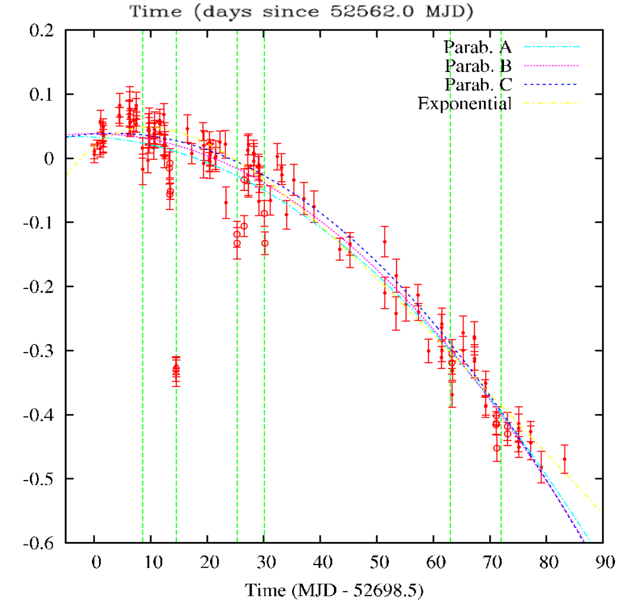
Spin up behavior is recovered in the 2^{nd} harmonic

XTE J1807-294

Large swings (100°) simultaneous to X-ray reflares

2^{nd} harmonic more stable





A model to explain phase shifts

- A pulse profile is built by the contribution of two signals at the same period.
  - ✓ If the two signals are exactly in antiphase ($\Delta\varphi = 180°$) variations of the relative strength modify only the total amplitude.
  - ✓ If the two signals are not in antiphase ($\Delta\varphi \neq 180°$) a **variation of the relative strength modify also the phase of the resulting pulse profile.**
- GR & SR effects (light bending and Doppler boost) introduce an offset between the two signals which depends on geometrical setting and spin rate of the pulsar.

Phase movements can be understood in terms of a geometrical effect triggered by variations of the amount of mass accreted instantaneously by each spots

- If firmly established this scenario would open the possibility to measure magnetic offset angle θ, and inclination I (Riggio et al., in prep.)

Timing results, a review

	ν (Hz)	$d\nu/dt$ ($\times 10^{-13}$ Hz/s)	
• IGR J00291+5934	598.892	11.1 ± 1.6	Burderi et al. 2006, ApJ
• XTE J1751-305	435.318	5.6 ± 1.2	Papitto et al. 2008, MNRAS
• SAX J1808.4-3658	400.975	4.4 ± 0.8	Burderi et al. 2006, ApJL (see also Hartman et al. 2008)
• XTE J1814-338	314.356	-0.67 ± 0.14	Papitto et al. 2007, MNRAS
• XTE J1807-294	190.624	1.2 ± 0.3	Riggio et al. 2008, ApJ
• XTE J0929-314	185.105	-0.55 ± 0.04	Di Salvo et al. 2007, AIP (see also Galloway et al. 2002)

• Faster spinning objects spin up because of accretion

• Strong indication that the rotational behavior during accretion is determined by the magnetic field or the secular accretion rate rather than by the actual spin

SAX J1808.4-3658: orbital evolution

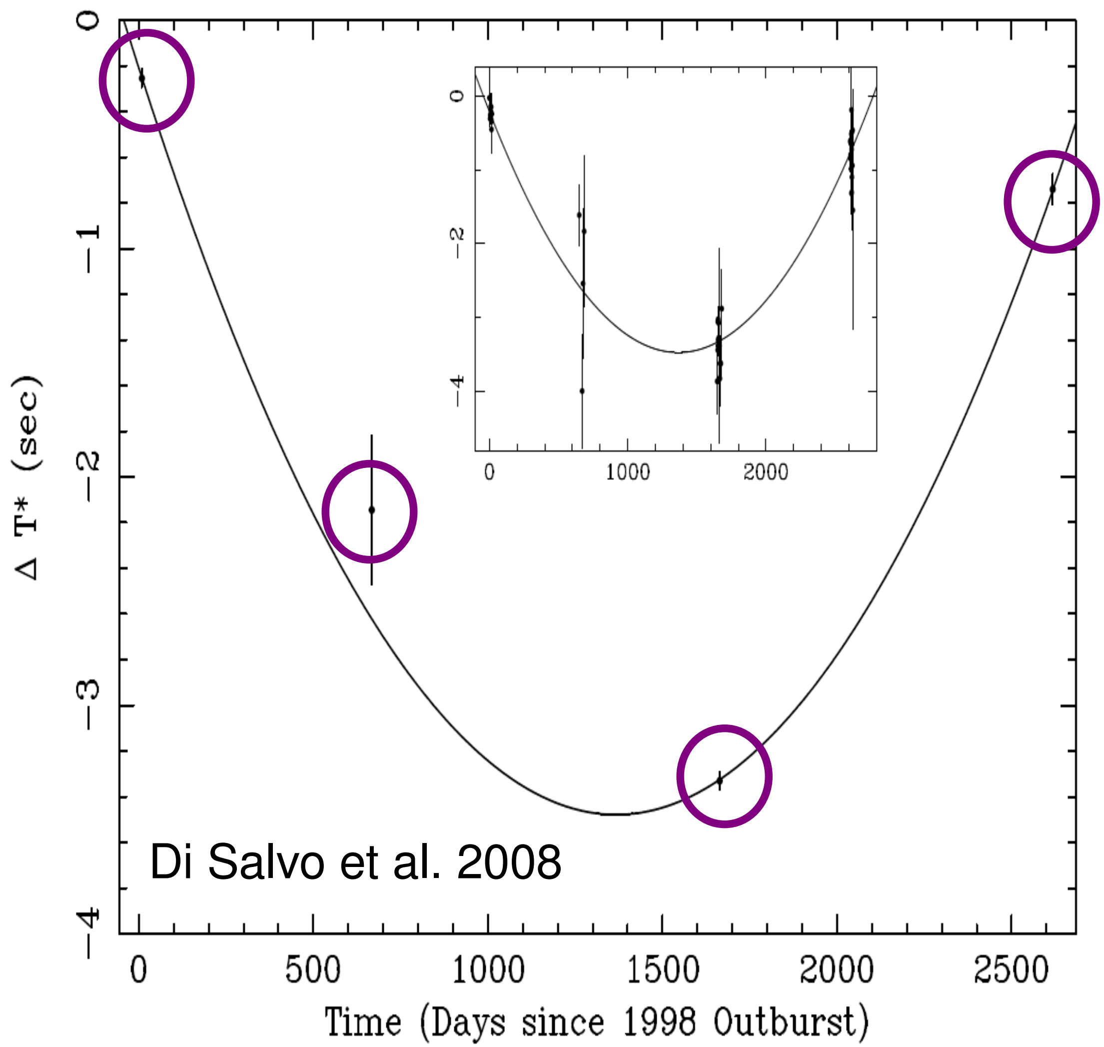
Four outbursts since discovery – 1998, 2000, 2002, 2005

The orbit is expanding at a rate:
$dP_{ORB}/dt = (3.40 \pm 0.12) \times 10^{-12}$ s/s

The companion must be fully convective or degenerate

...but the measured value rules out a conservative scenario

We propose that the source has a Black Widow Pulsar's behavior and lies between accretors and ejectors



Conclusions & Future

- AMSPs can have a bimodal behavior for what concerns:
  - Spin Frequency derivatives
    3-4 out of 6 spin up at 10^{-12}-10^{-13} Hz/s rate (B fields 10^8G)
    2 out of 6 spin down at 10^{-14} Hz/s rate (B fields 10^9G)
  - Phase stability: according to our preliminary model (Riggio et al., in prep.):

    Stability may be related to only one spot visible (i<45°)
    Phase oscillations appears when both spot are visible and there is a variation of the instantaneous accretion rate on each of them

- Future: XTE is at the end of its mission.

  XMM-Newton may play a fundamental role in the discovery of new sources as EPIC CCDs has timing (0.03ms resolution on PN) and photon collecting capabilities to do it
  (Kuster et al. 2002, Wijnands 2008)