X-ray Timing of Isolated Neutron Stars

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Kaplan & van Kerkwijk 2005, ApJ, 628, L45
Kaplan & van Kerkwijk 2005, ApJ, 635, L65

Isolated Neutron Stars:
from the Interior to the Surface
April 2006

X-ray Timing: Goals

- Measure $\dot{P}$, get:
  - magnetic field *B*
  - spin-down luminosity $\dot{E}$
  - spin-down age τ

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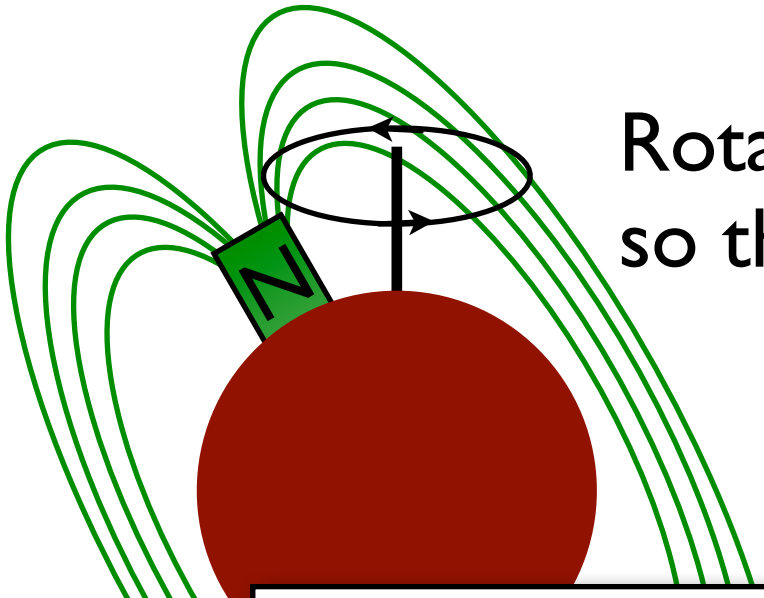
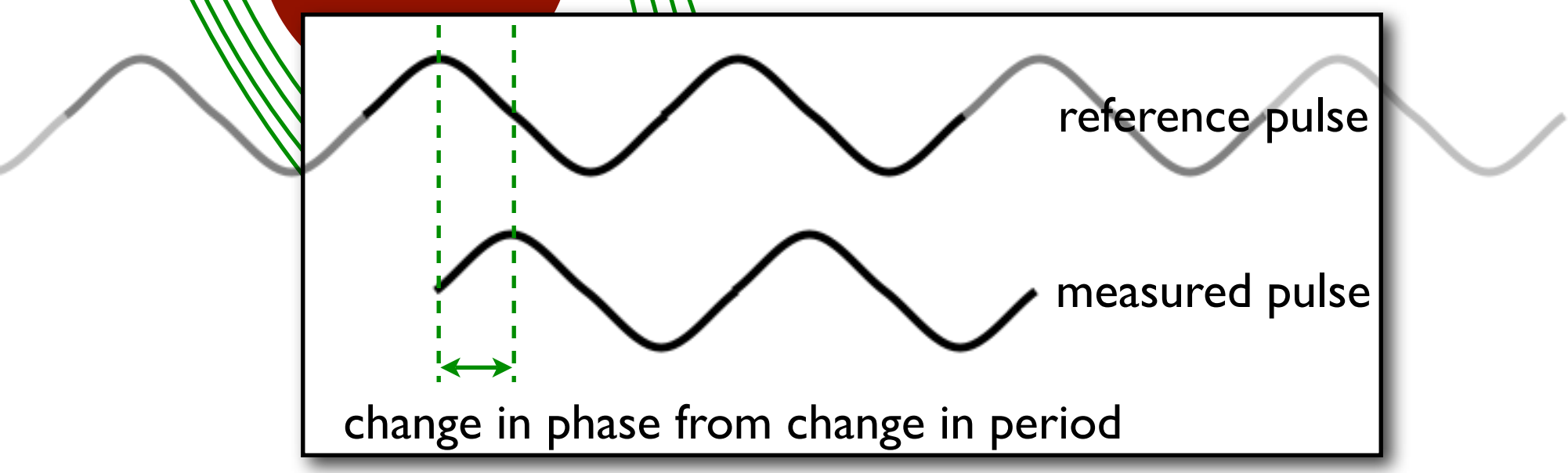
- Measure $\dot{P}$, get:
  - magnetic field *B*
  - spin-down luminosity $\dot{E}$
  - spin-down age τ
- Compare magnetic field to spectrum
- Assess noise/torques (like AXPs):
  - glitches
  - precession
  - random noise

Timing: Integer Astronomy



Rotating dipoles lose energy,
so they slow down

If we can measure the slow-down,
we can measure the magnetic field



X-ray Timing: Difficulties

- Need to count all cycles to avoid aliases
- Hard for INS:
  - hard to get data (just *Chandra* & *XMM*):
    - no (readily detectable) radio emission
    - soft X-rays: no *RXTE*
  - long P, so takes a long time to accumulate phase shift

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very low

$$\phi = \frac{t}{P} - \frac{\dot{P}t^2}{2P^2} + \ldots \quad |\Delta\phi_{\dot{P}}| \propto \dot{E}Pt^2$$

RX J0720.4-3125

- Used *Chandra* ACIS continuous-clocking observations designed for timing:
  - 4 observations geometrically spaced over 1 month
  - repeated 6 months later
- Combined with other observations:
  - first *Chandra*
  - then *XMM*, *ROSAT*

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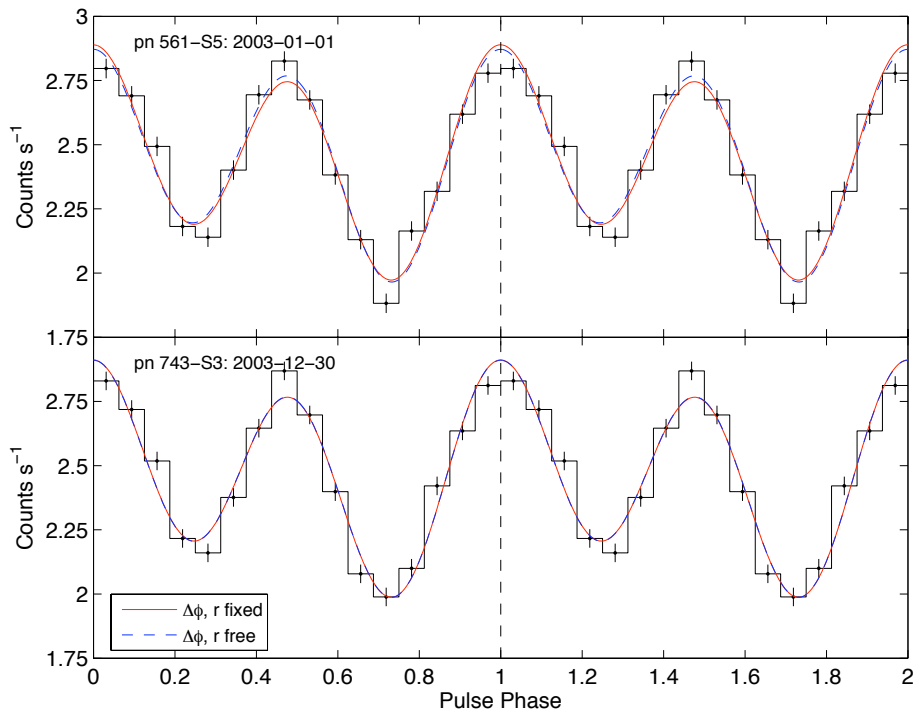
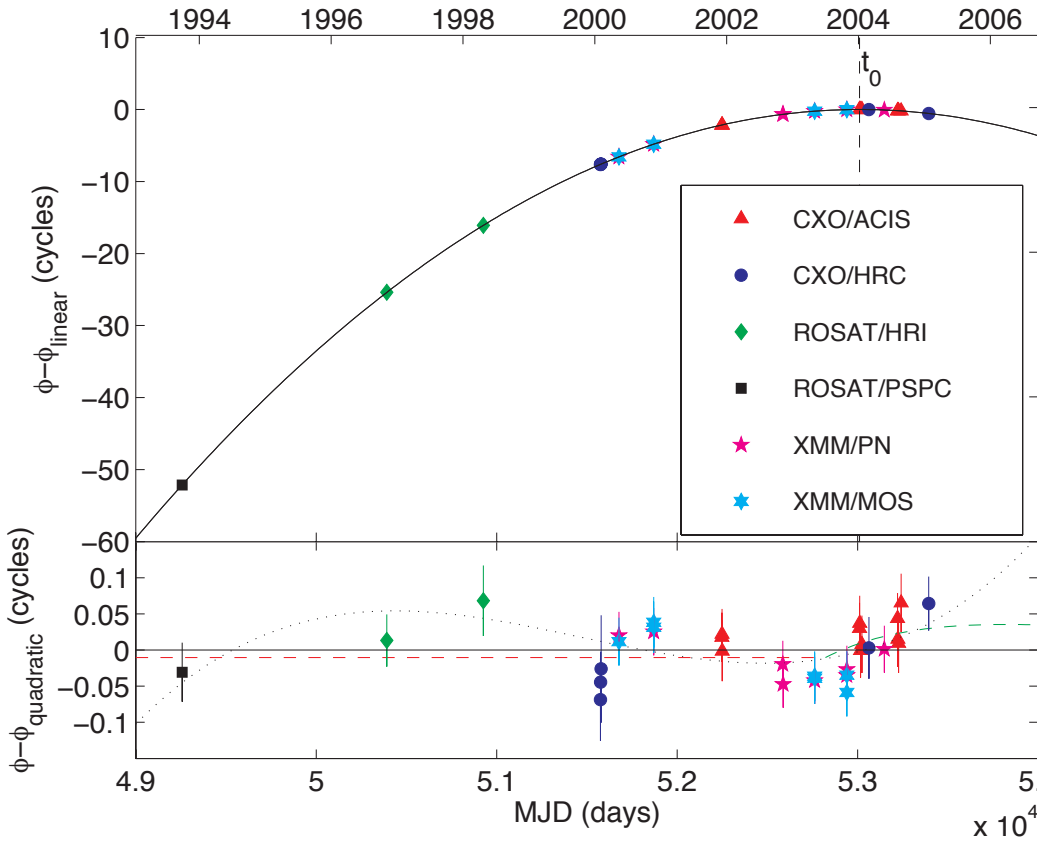
Note: Variability seen in spectrum/pulse shape (Haberl et al.; de Vries et al.; Vink et al. 2004)

RX J1308.6+2127 (RBS 1223)

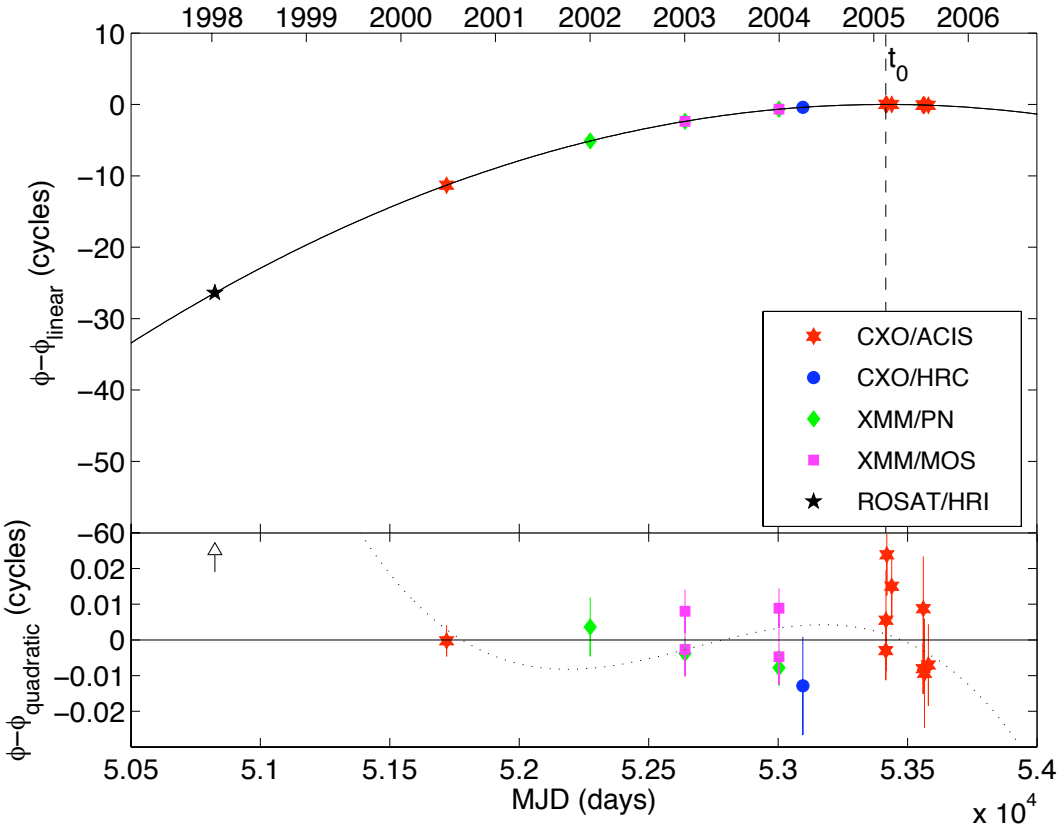
- Similar set of new *Chandra* data
- Fewer *XMM* and *ROSAT* observations to match with
- Pulse profile is double-peaked



Results: Timing Solutions



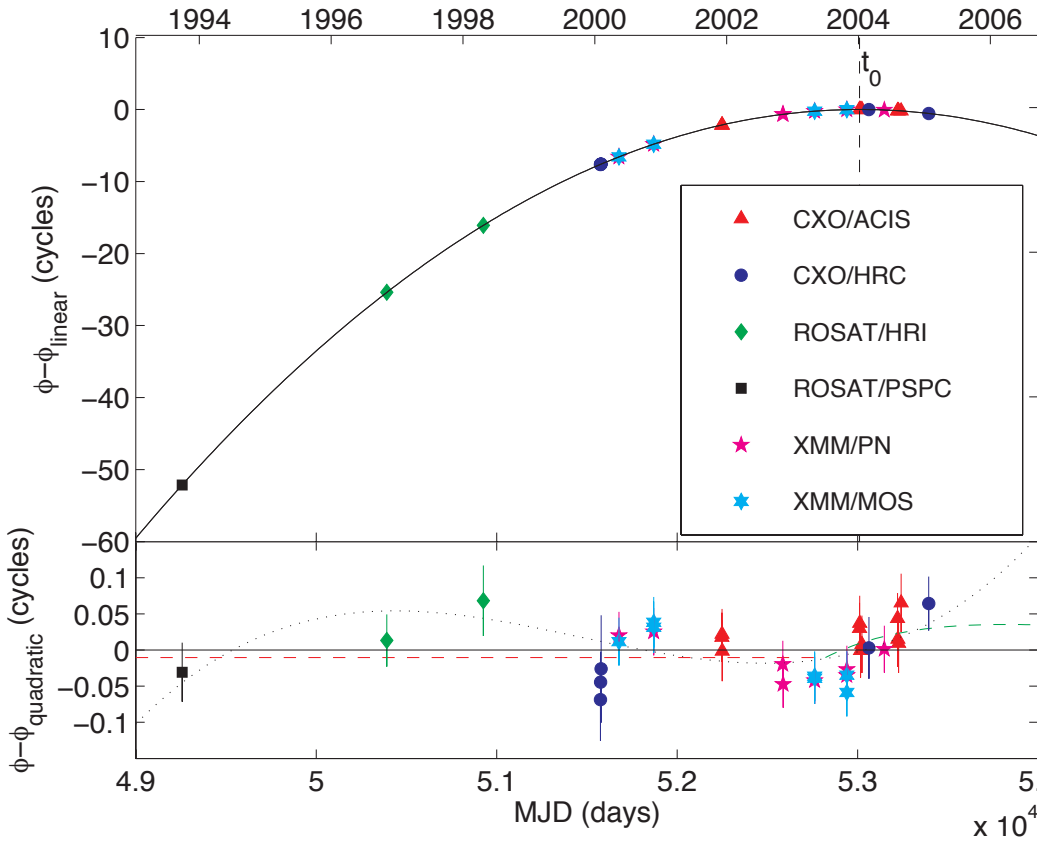
RX J0720



RX J1308

Results: Timing Solutions

Kaplan & van Kerkwijk '05a,b



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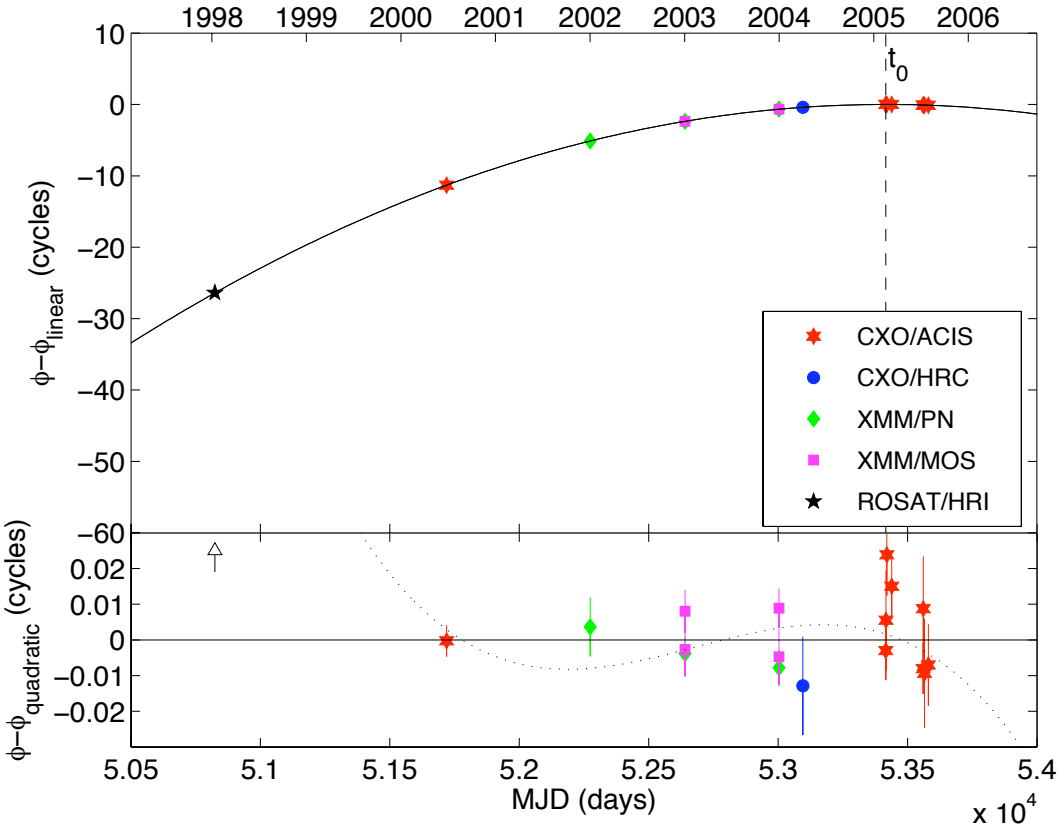


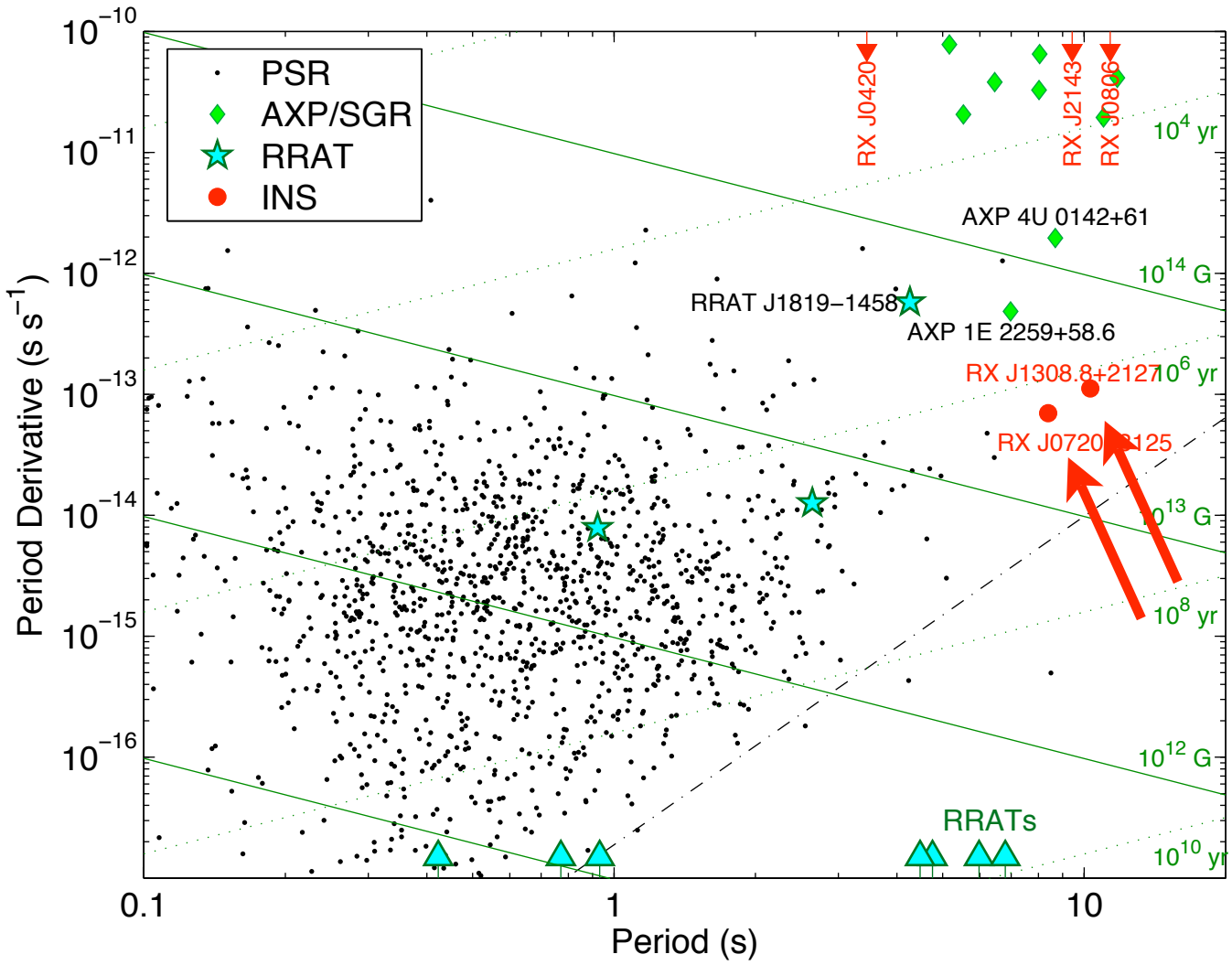
RX J1308

No cycle ambiguities!

General Results

	RX J0720	RX J1308
Period (sec)	8.391115532(26)	10.31252206(2)
$\dot{P}$ (s/s)	$6.983(22)\times10^{-14}$	$1.120(3)\times10^{-13}$
***B* (G)**	2.4×10^{13}	3.4×10^{13}
τ (Myr)	1.9	1.5
$\dot{E}$ (erg/s)	4.7×10^{30}	4.0×10^{30}
rms (sec)	0.31	0.010

In the Population



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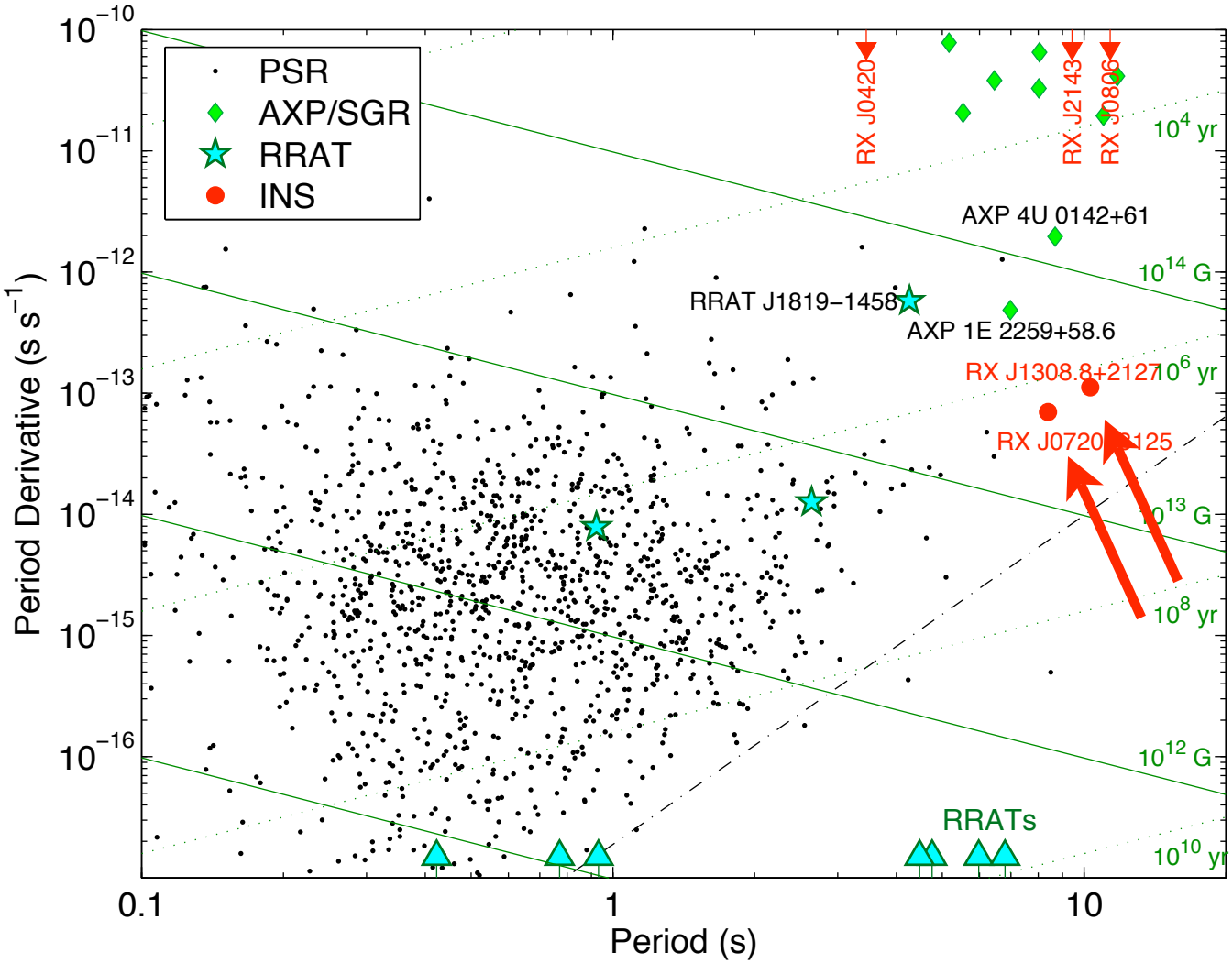
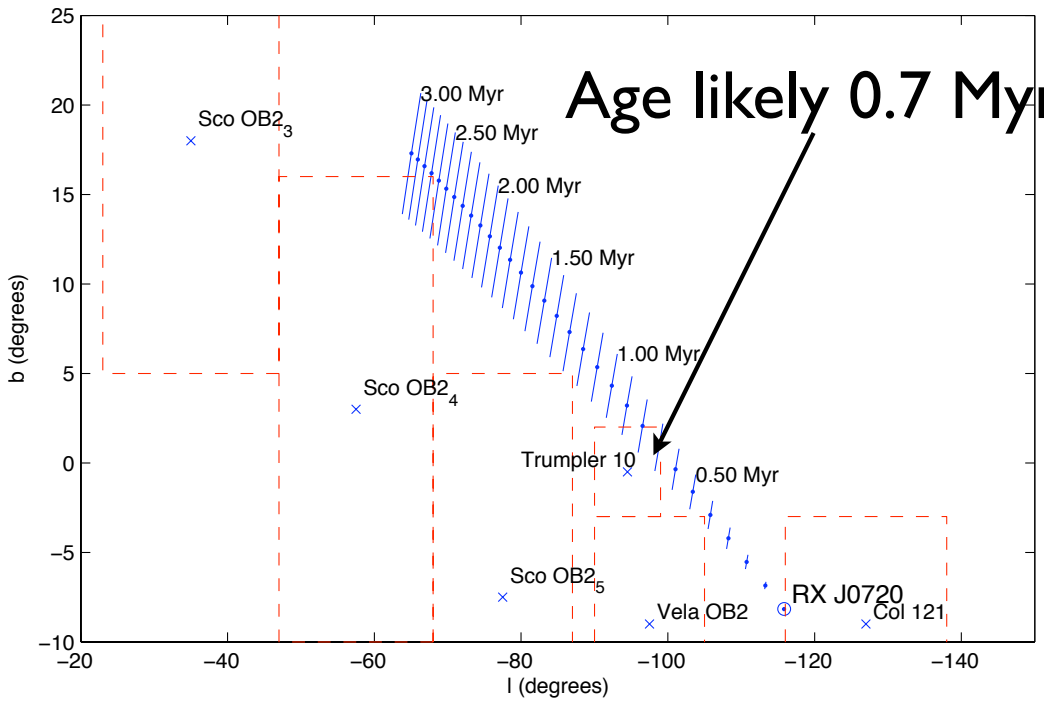


- What about the RRATs (McLaughlin et al. '06)?
- Also see Popov et al. ('06)

Implications: Ages & Energetics

- Spin-down age ~2 Myr
  - Cooling ages and μ give ~0.5 Myr
  - Could be long birth P?
  - High braking index (~9)?
  - Or decouple τ_{sd} & τ_{cool} with accretion & second SN in binary?



(also see Motch et al. '03)

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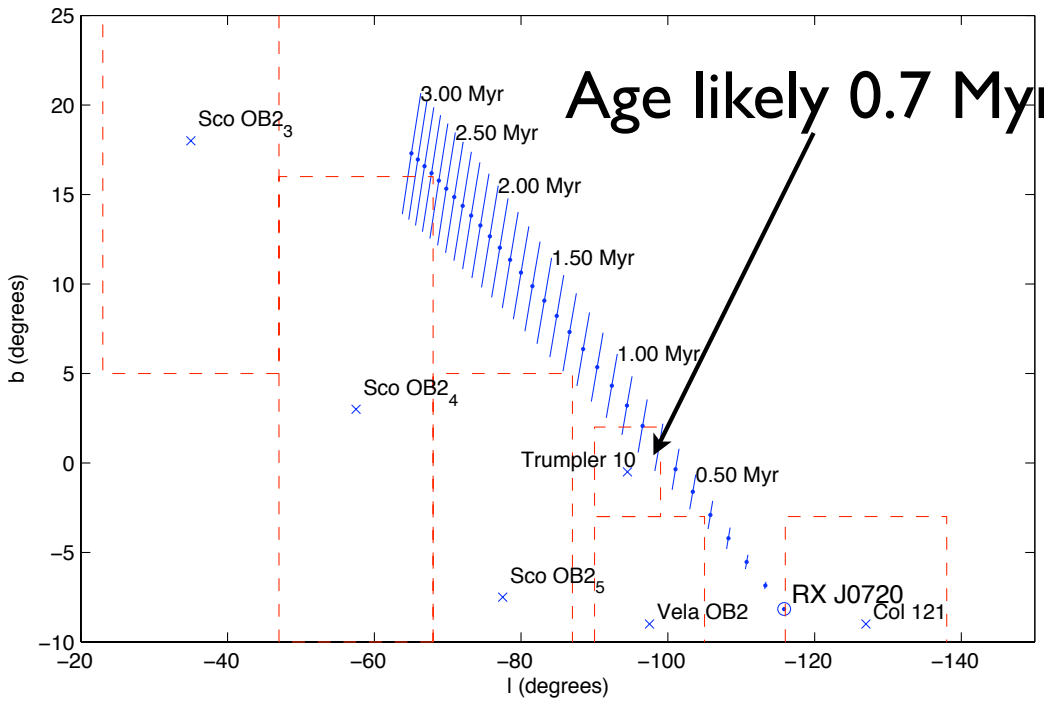
- Low $\dot{E}$: little if any non-thermal emission expected
  - $L_X/\dot{E} \sim 40$
  - vs. 10^{-3} for non-thermal emission from PSRs



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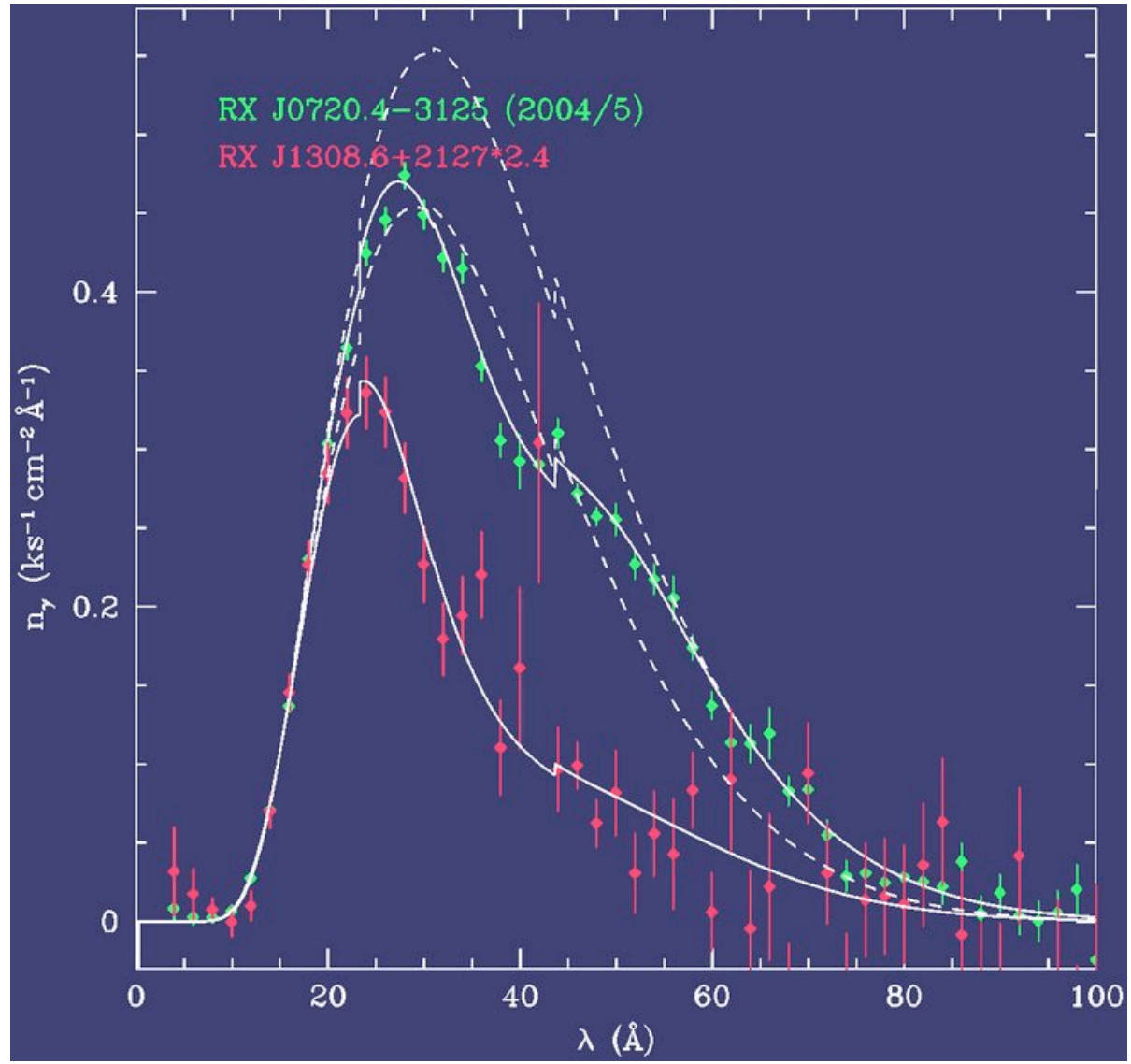
Implications: Spectral Features

- Both sources: broad, low-energy absorption features in X-ray spectra
- Similar energies
- Very different strengths
- But:
  - $B(0720) = 2.4\times10^{13}$ G
  - $B(1308) = 3.4\times10^{13}$ G



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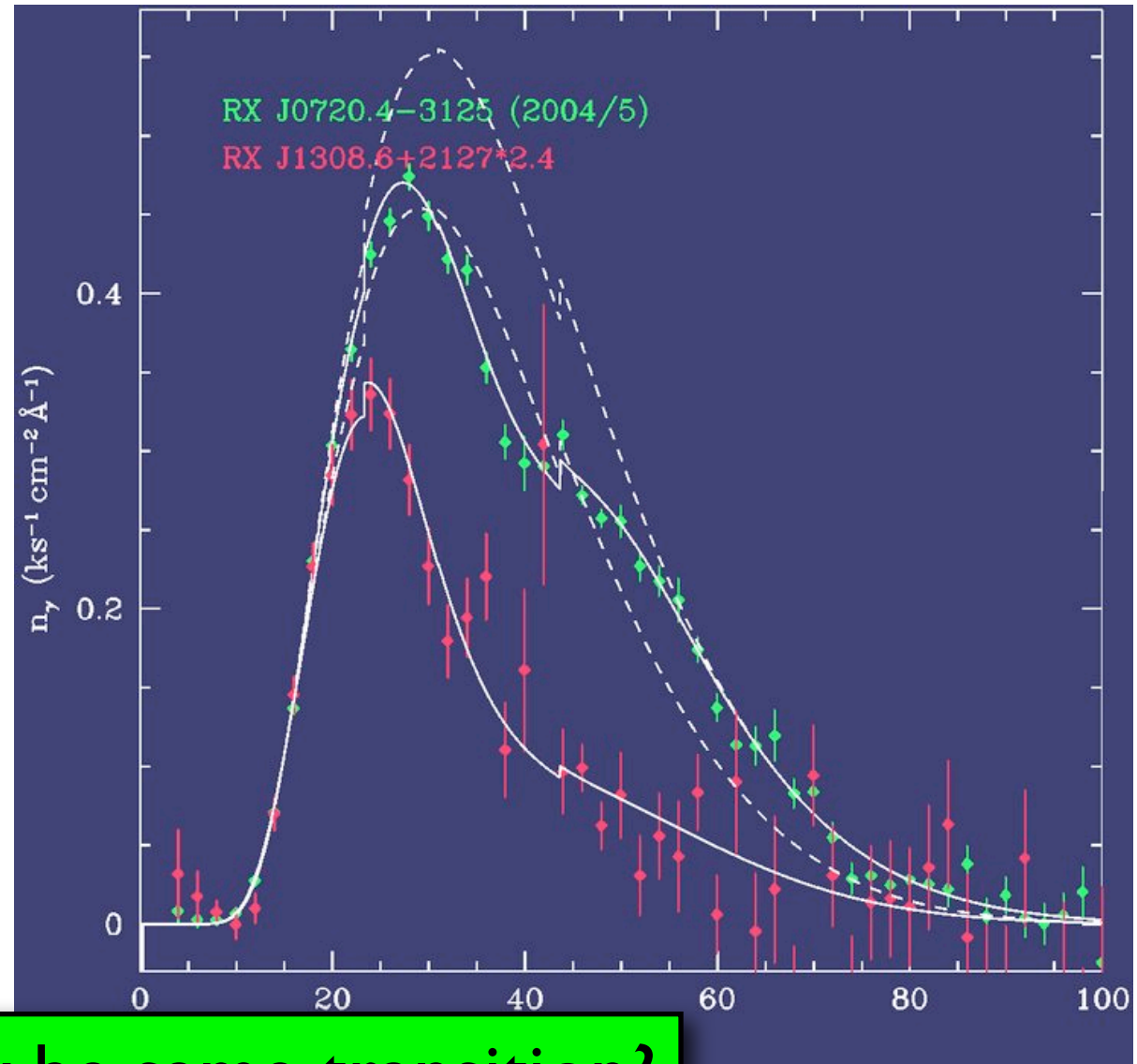
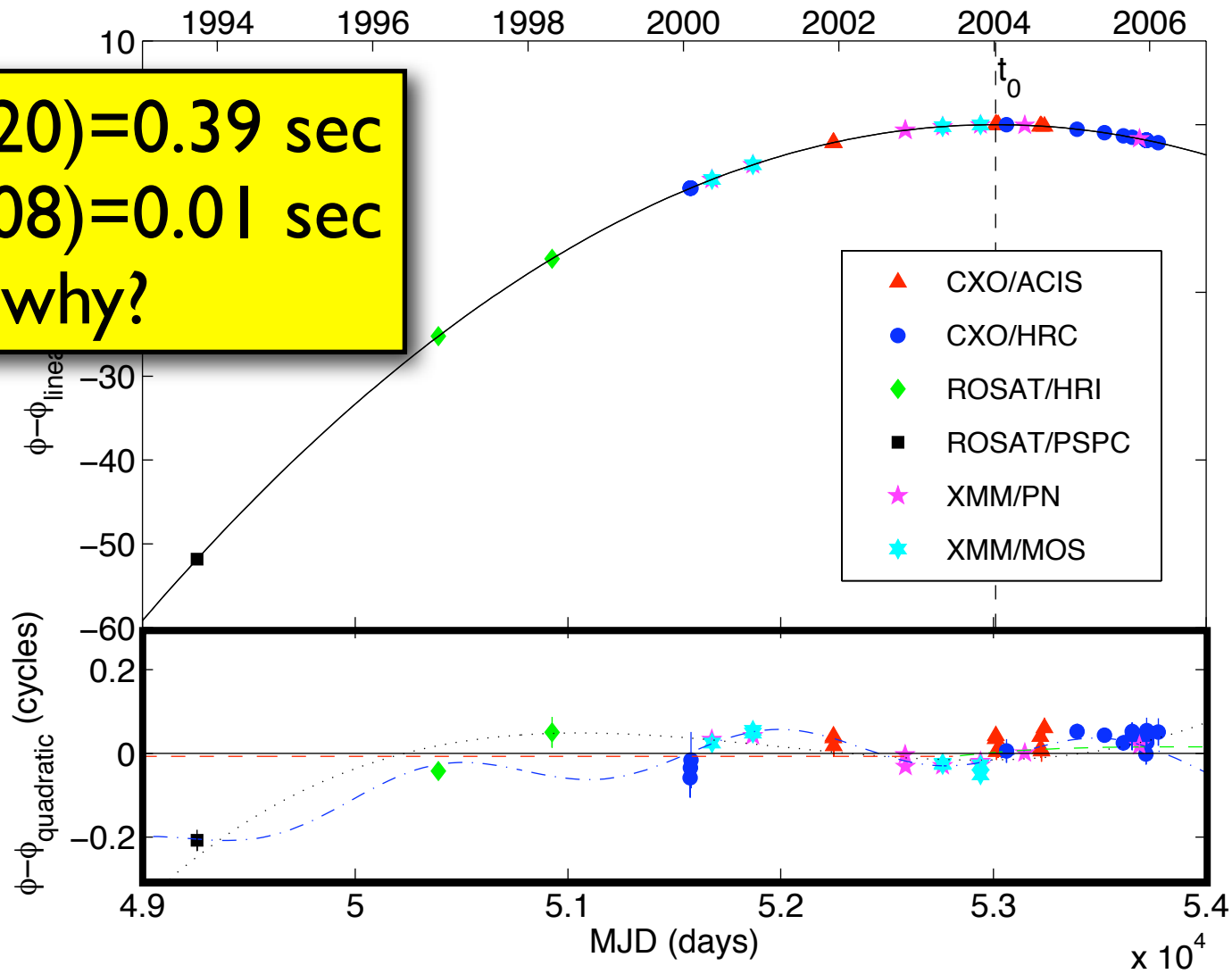


Can they be same transition?

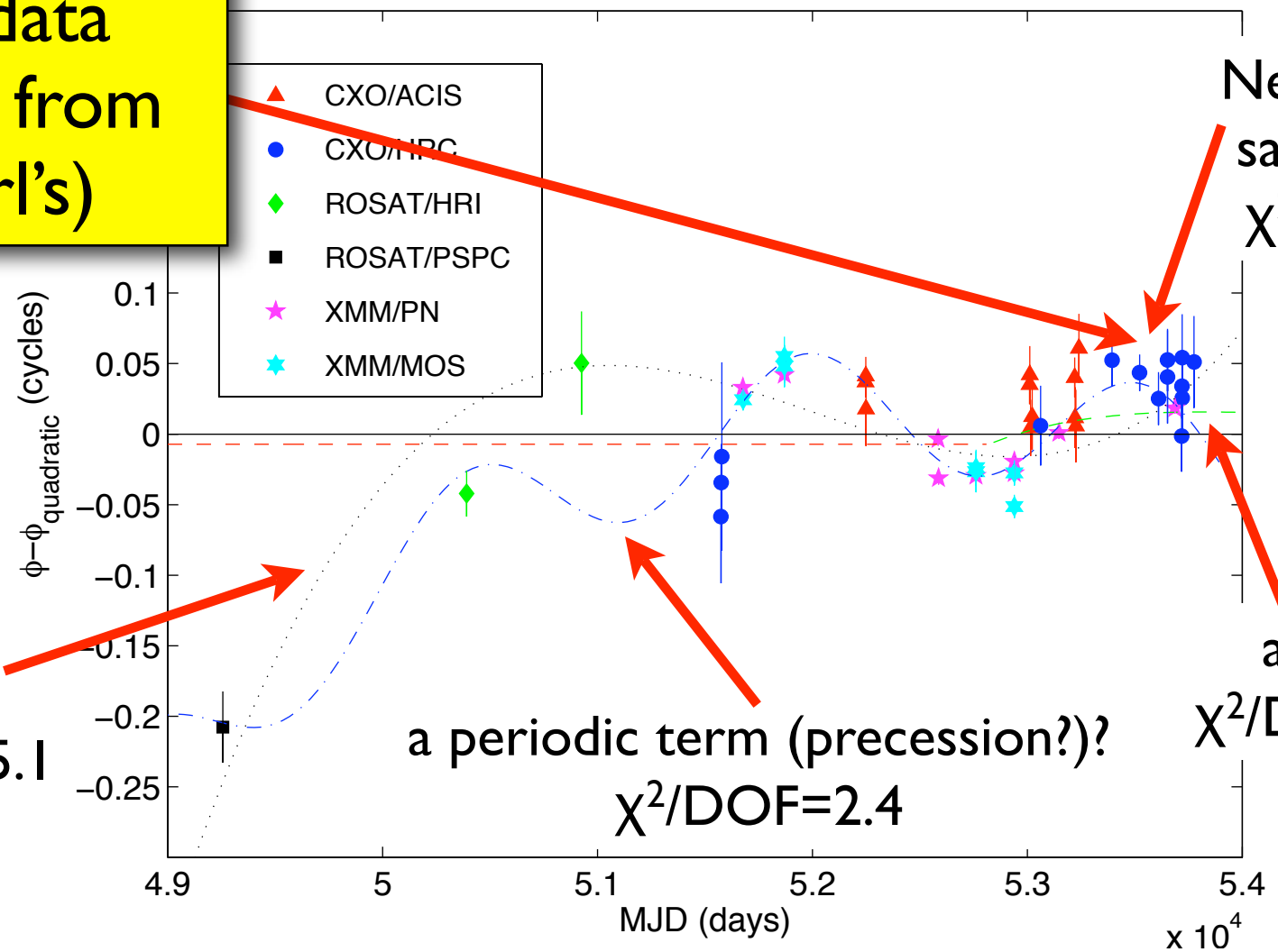
RX J0720: Timing Noise

rms(0720)=0.39 sec
rms(1308)=0.01 sec
why?



RX J0720: Timing Noise

(new data *different* from Haberl's)



New data show same behavior
χ^2/DOF=11.9

a cubic?
χ^2/DOF=5.1

a periodic term (precession?)?
χ^2/DOF=2.4

a glitch?
χ^2/DOF=11.6

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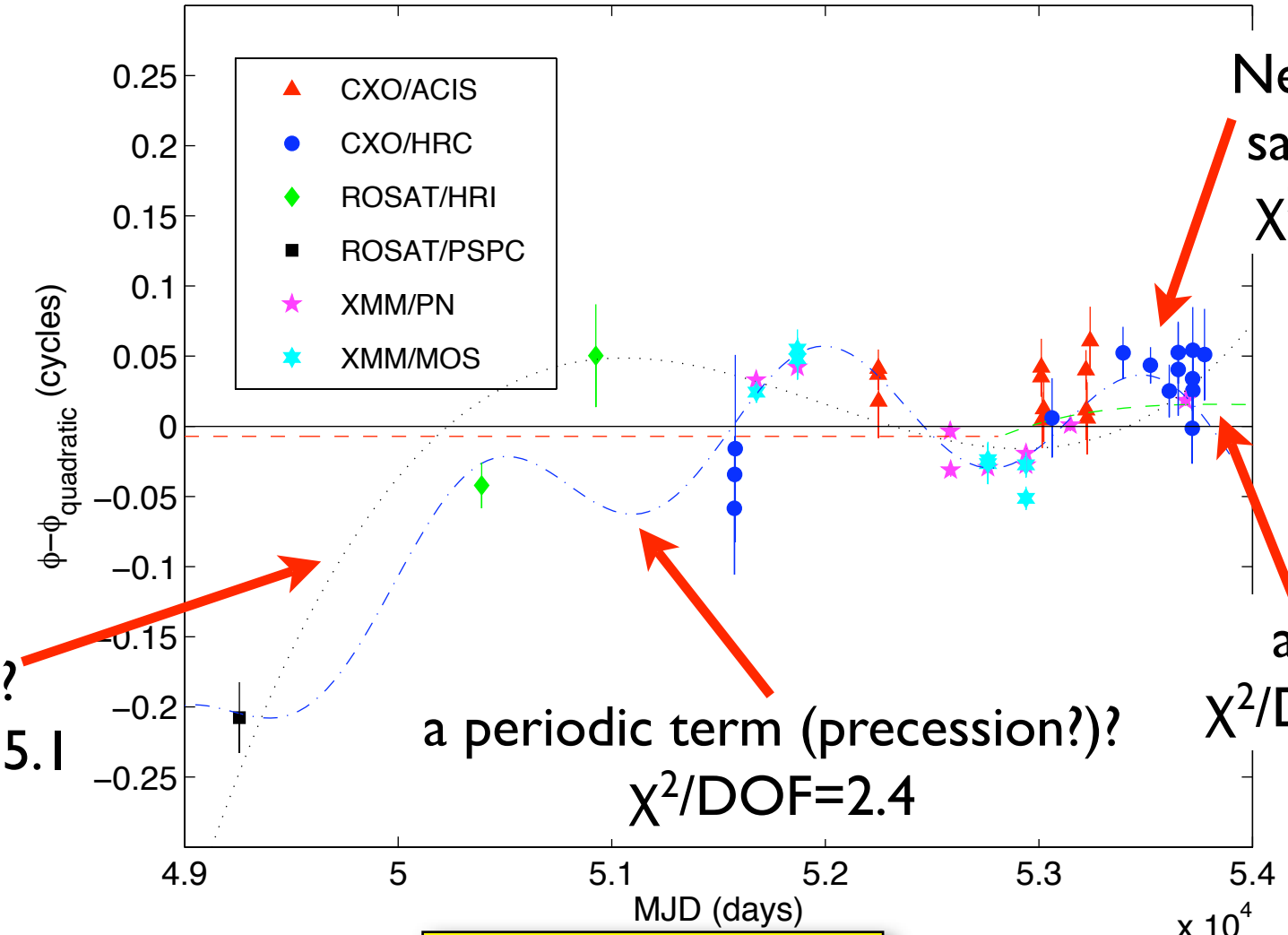

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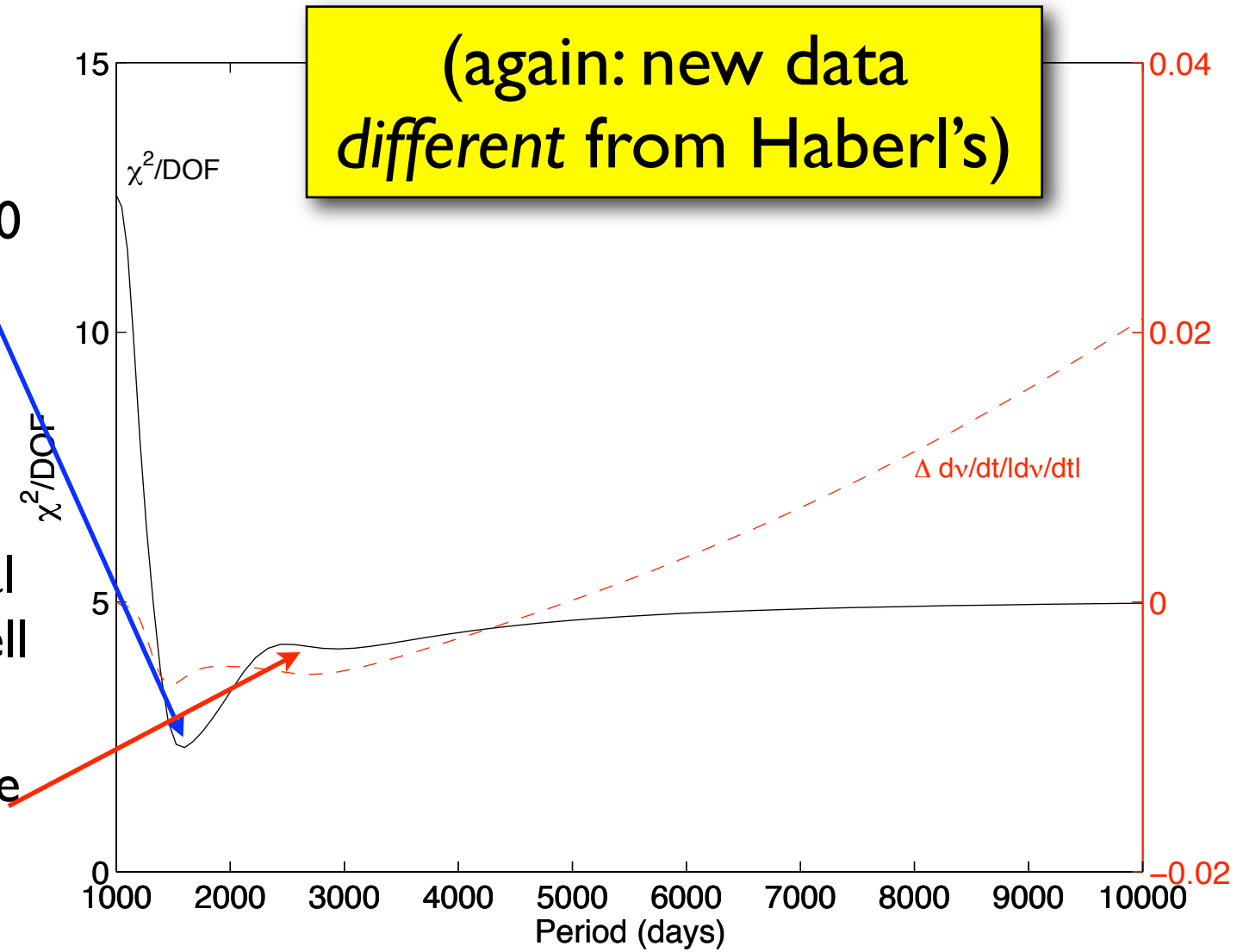
but see AXPs!

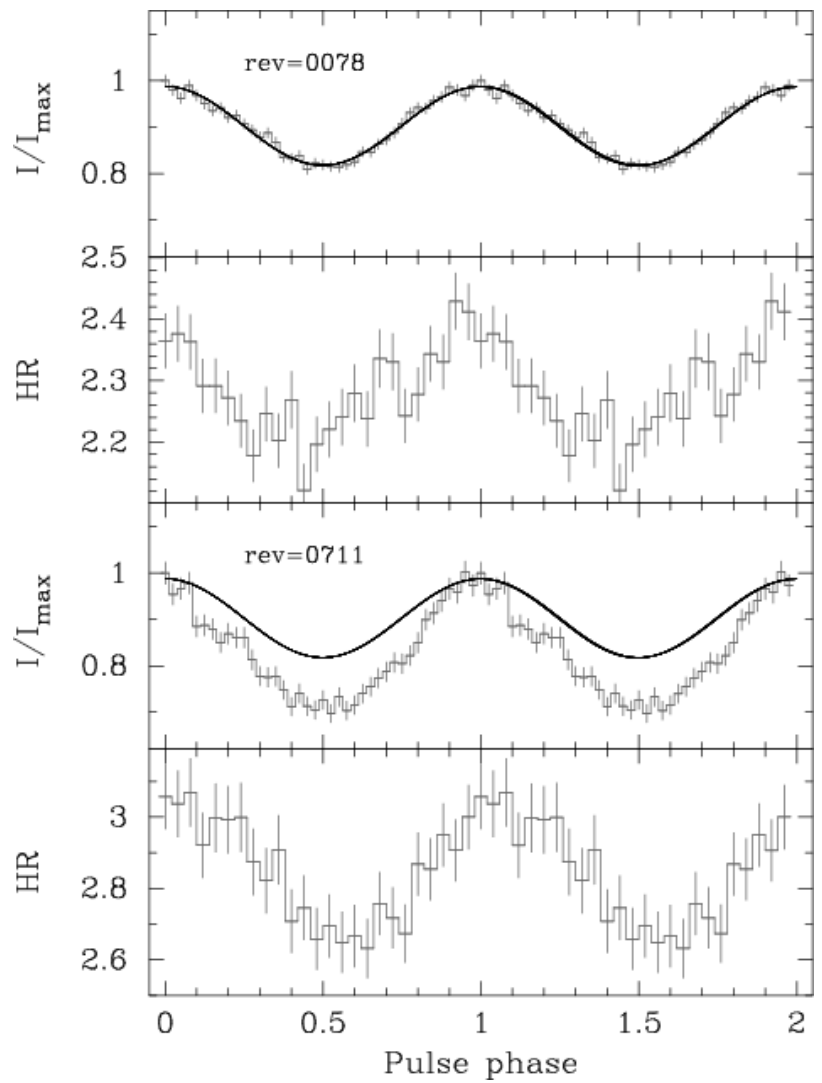
Periodic Residuals?

- Best period: 1500 days=4.3 yrs
- Only see ~2.5 periods
- But need high-order polynomial (>9) to do as well
- No evidence for ~7 yr period (see Haberl et al.)



Explanations

- Secular evolution?
  - Pulse profile known to change
- Timing noise?
  - Δ_8=-0.5 agrees with trend from PSRs



(de Vries et al. 2004; Vink et al. 2004)

Conclusions

- Timing solutions for 2/7 INSs (2/5 with periods)
- Already helping unravel sources
- Still have puzzling behavior
- Need to:
  - Monitor these sources
  - Get solutions for others