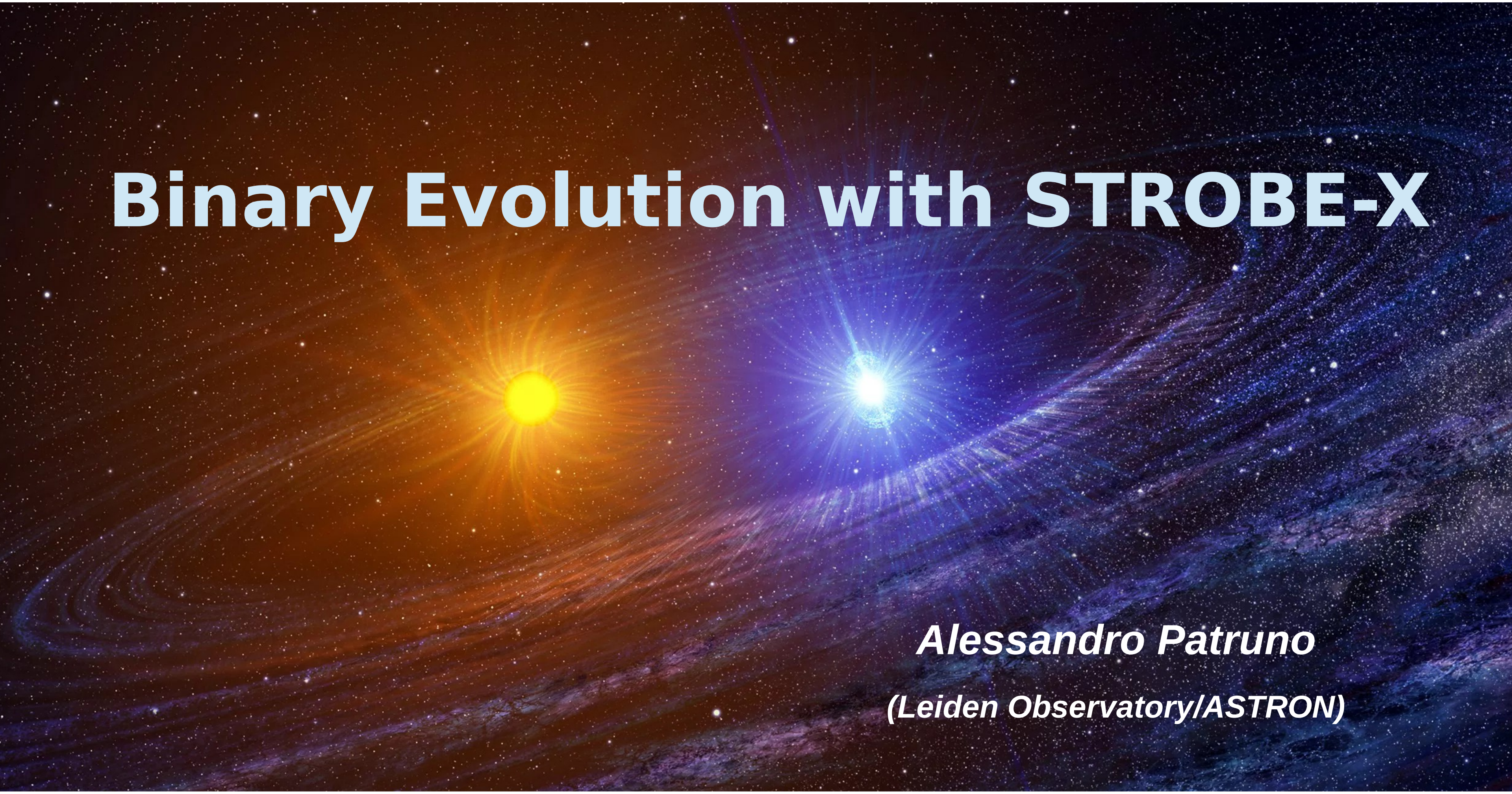
Binary Evolution with STROBE-X



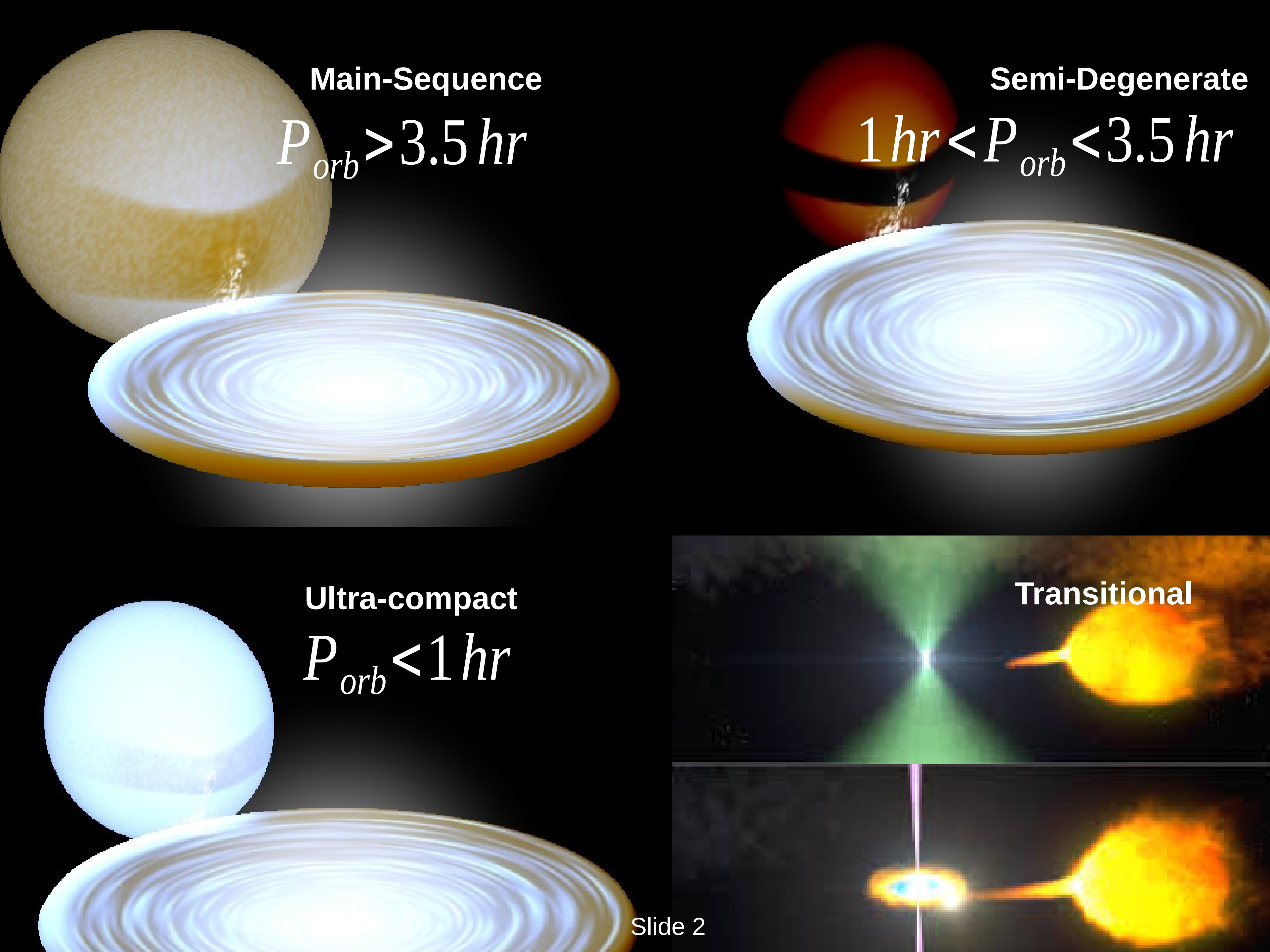
Alessandro Patruno

(Leiden Observatory/ASTRON)

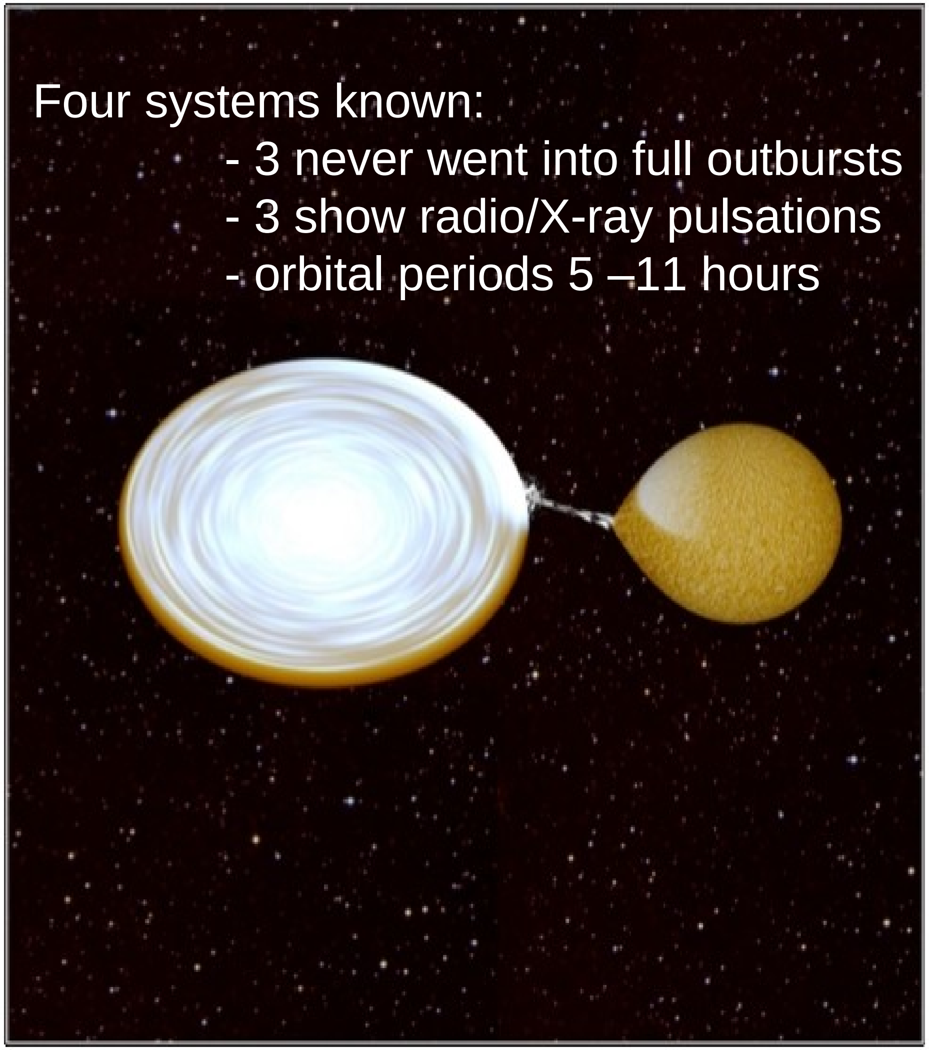
Universiteit Leiden
The Netherlands

ASTRON
Netherlands Institute for Radio Astronomy

NWO
Netherlands Organisation for Scientific Research


Main-Sequence
$P_{orb} > 3.5\,hr$
Semi-Degenerate
$1\,hr < P_{orb} < 3.5\,hr$
Ultra-compact
$P_{orb} < 1\,hr$
Transitional

Transitional Millisecond Pulsars

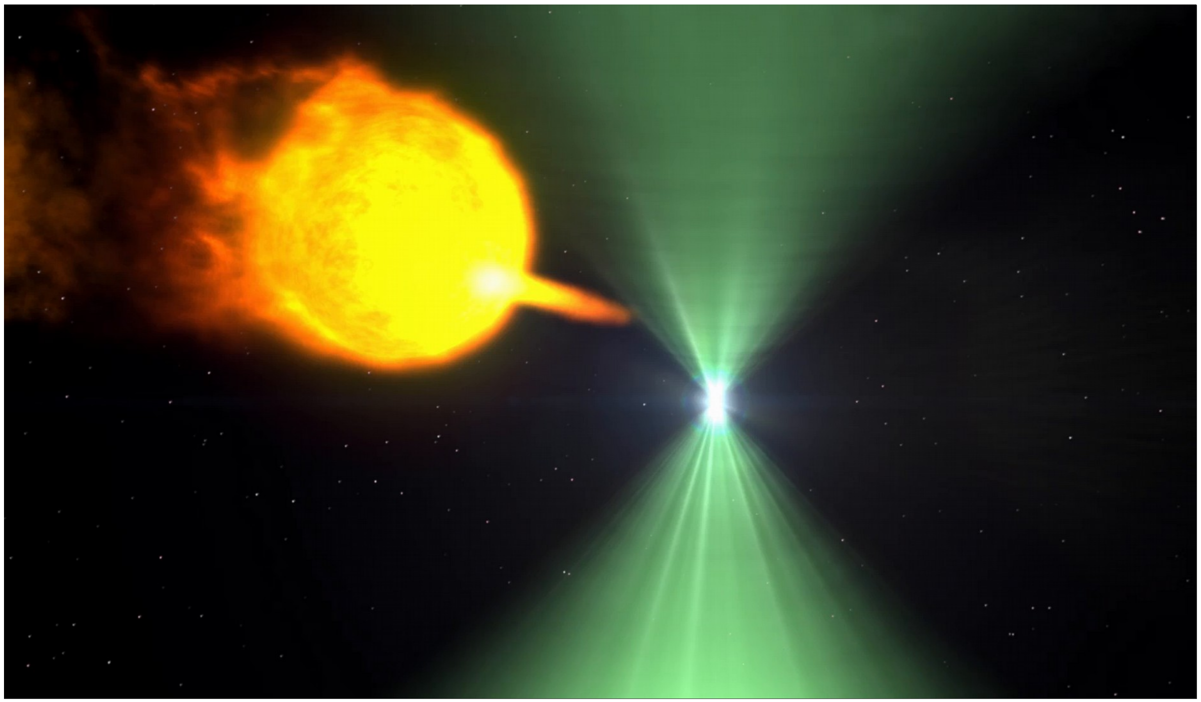


Timeline of PSR J1023+0038

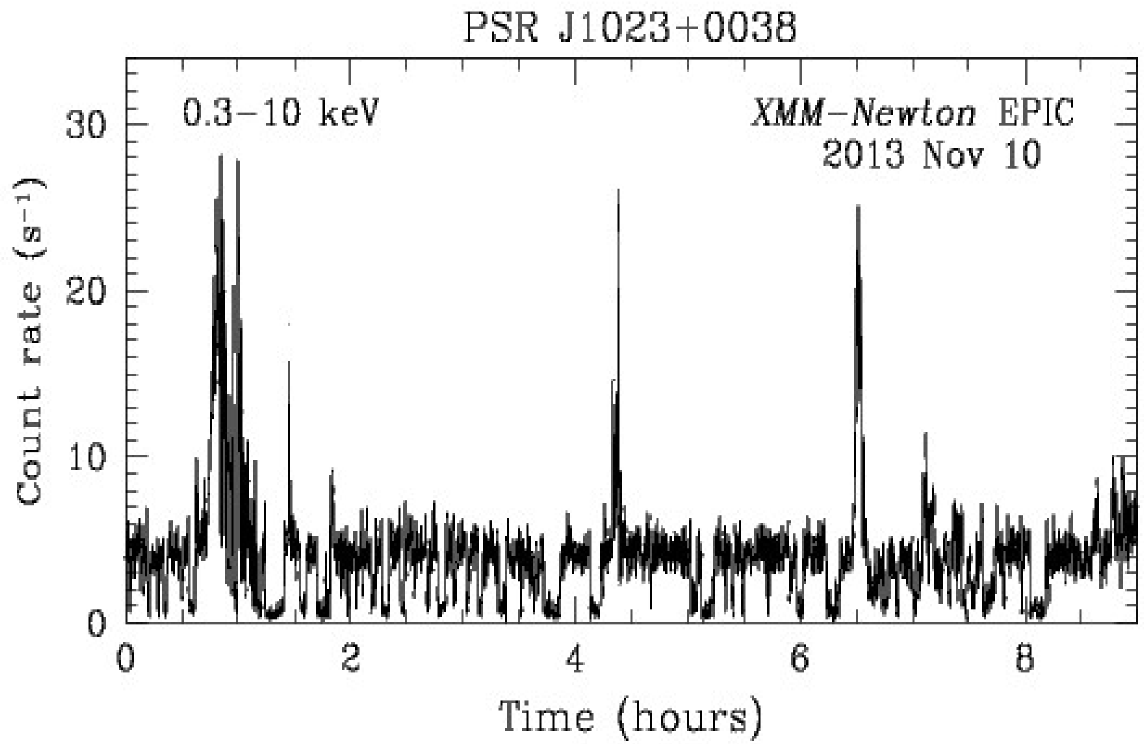
LMXB

Radio MSP

Archibald+ 2009



Unexplained Flickering



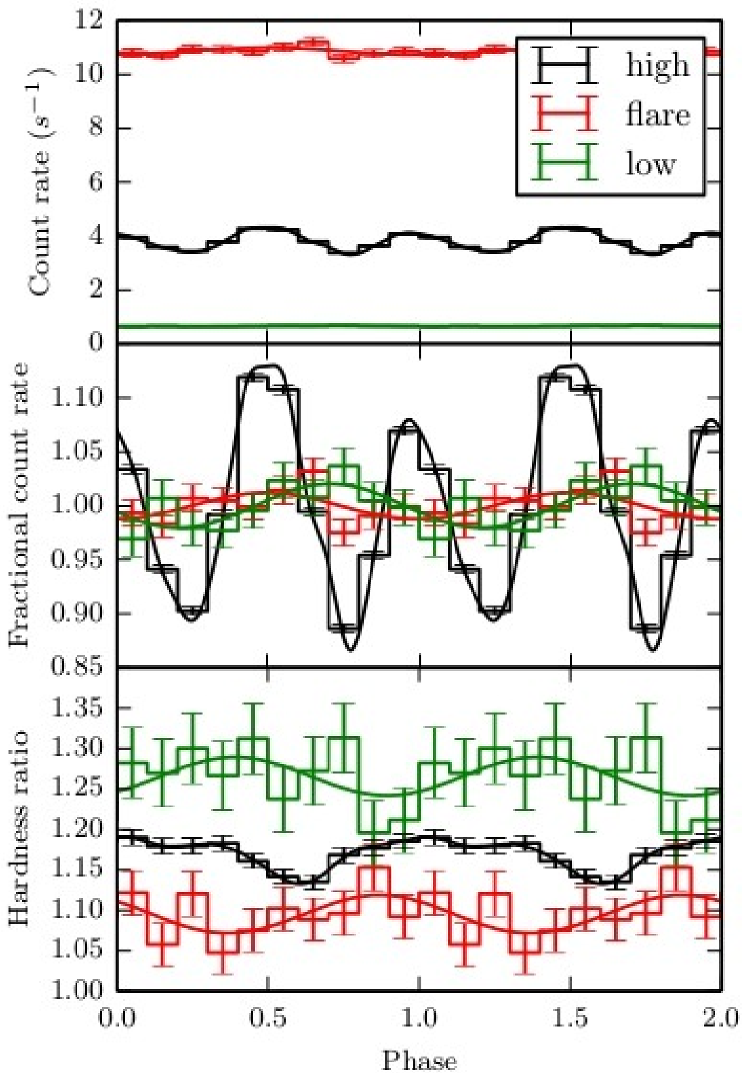
Patruno+ 2014
Bogdanov+ 2015
Kong+ 2014
Tendulkar+ 2014
De Martino+ '10,'13
Bassa+ '14

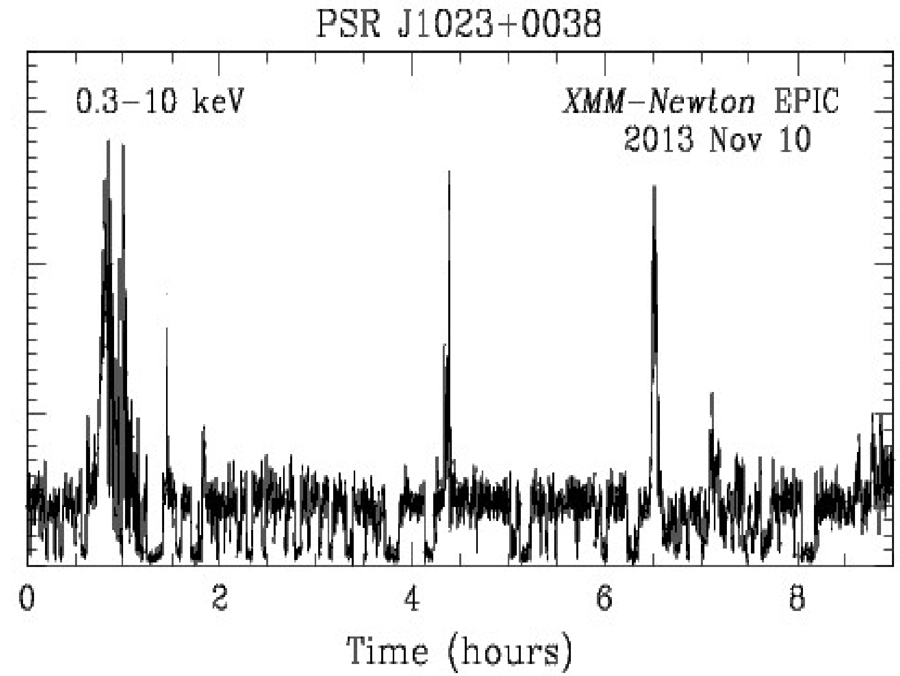
X-Ray Flickering: 10-1000 s

Luminosity: 1e32 – 1e34 erg/s

qLMXB?

The first accretion powered **quiescent** LMXB

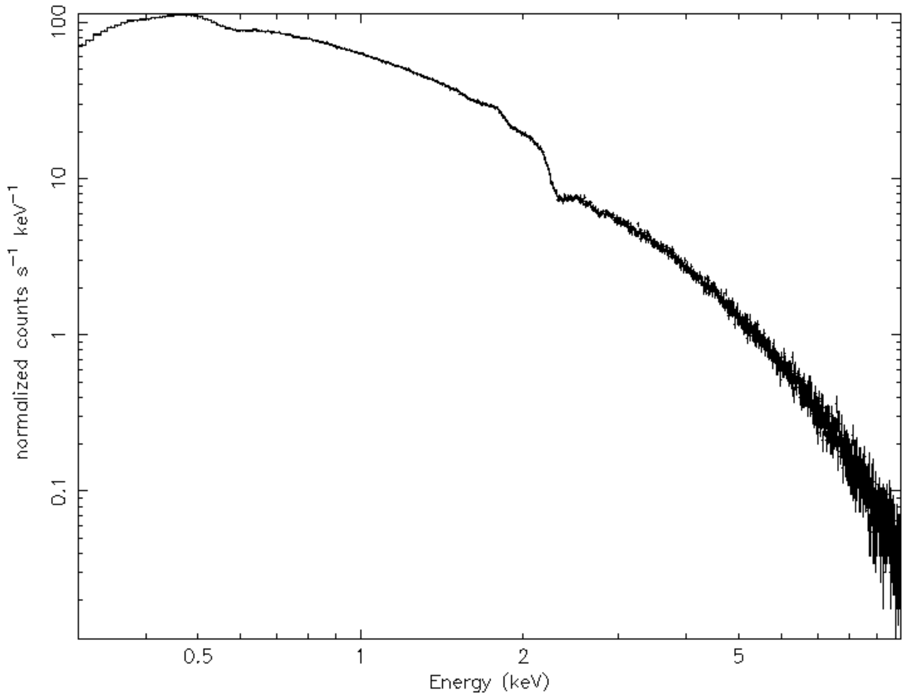




Intermittent Pulses!

Archibald+ '15

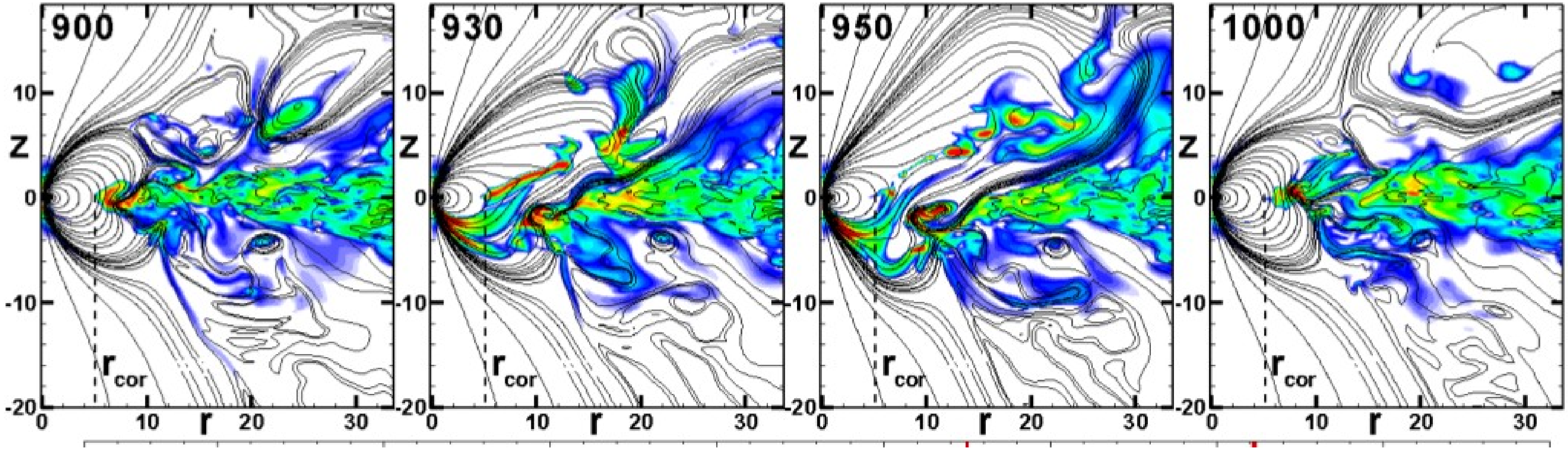
XRCA observing tMSPs



Simulations of XRCA on the tMSP PSR J1023+0038 show that the expected (0.3-10 keV) count rate is about 105 ct/s (compared to the actual XMM-Newton ~5 ct/s).

With this count rate one can measure variations of the spin at a rate of 10^-15 Hz/s in about one day of continuous observations (today you need several months due to both the low count rate **and** the observational constraints dictated by XMM).

Probing the Accretion Flow



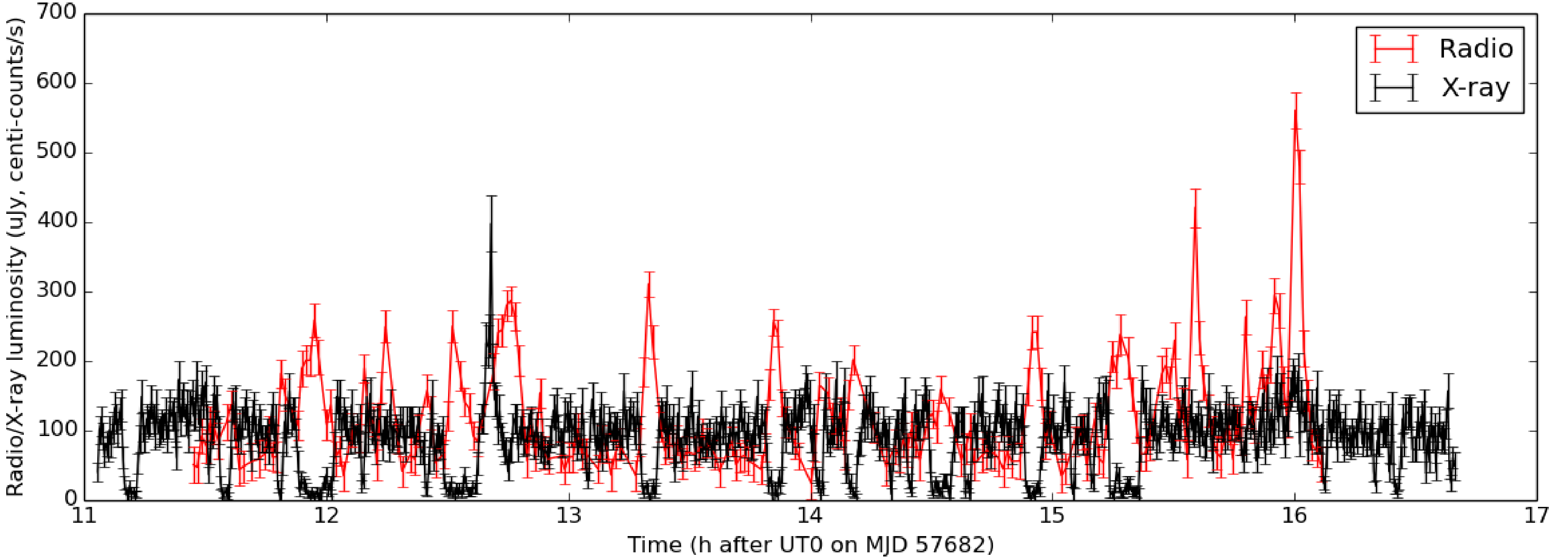
With XRCA you can probe the accretion flow as it moves around the inner disk regions on timescales of the order of 1 second (now it's tens to hundreds of seconds).
In this way one can easily probe different accretion flow theories and even the presence of a pulsar wind colliding with the accretion flow.

$$\tau_{\rm visc} \sim 3\alpha^{-4/5}\left[\frac{\dot{M}}{10^{16}\ \rm g/s}\right]^{-3/10}\left[\frac{M}{1\ M_\odot}\right]^{1/4}\left[\frac{R}{10\ \rm km}\right]^{5/4} s \longrightarrow$$

About 100 s
for R=10 km
Mdot ~ 1e13 g/s

(Simulation from Romanova, Patruno et al. in prep)

Outflows at low luminosity



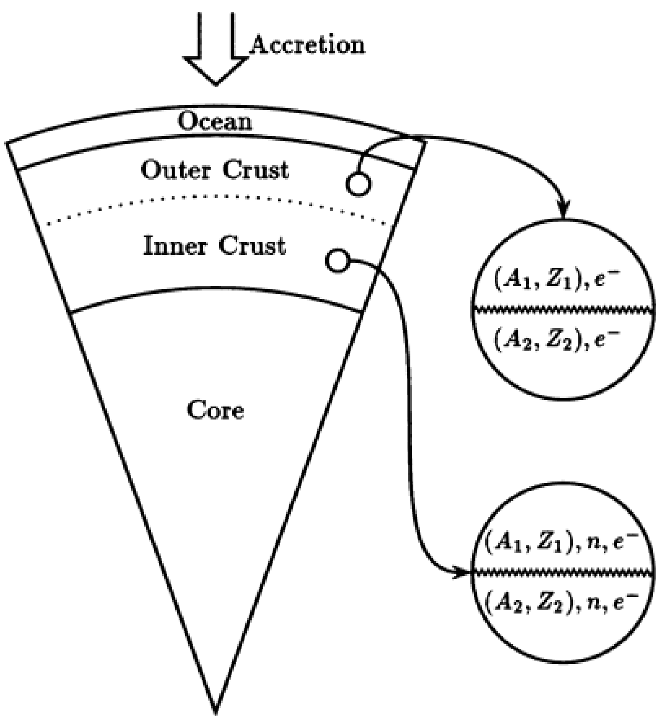
J-VLA & *Chandra* simultaneous observation

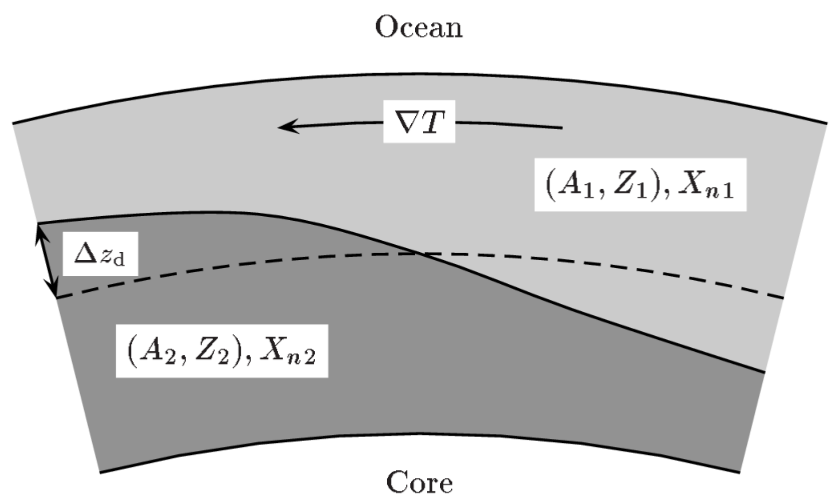
Bogdanov et al. in prep.

Gravitational Waves

The possibility to measure $\dot{\nu} \approx 10^{-16} - 10^{-15}\, Hz/s$ on timescales of days opens up the possibility to detect spin variations due to **gravitational waves**

E.g. crustal mountains: asymmetries in the **local** accretion rate and crustal composition can lead to asymmetric heat release (due to ‘deep crustal heating’), that will source a mass quadrupole





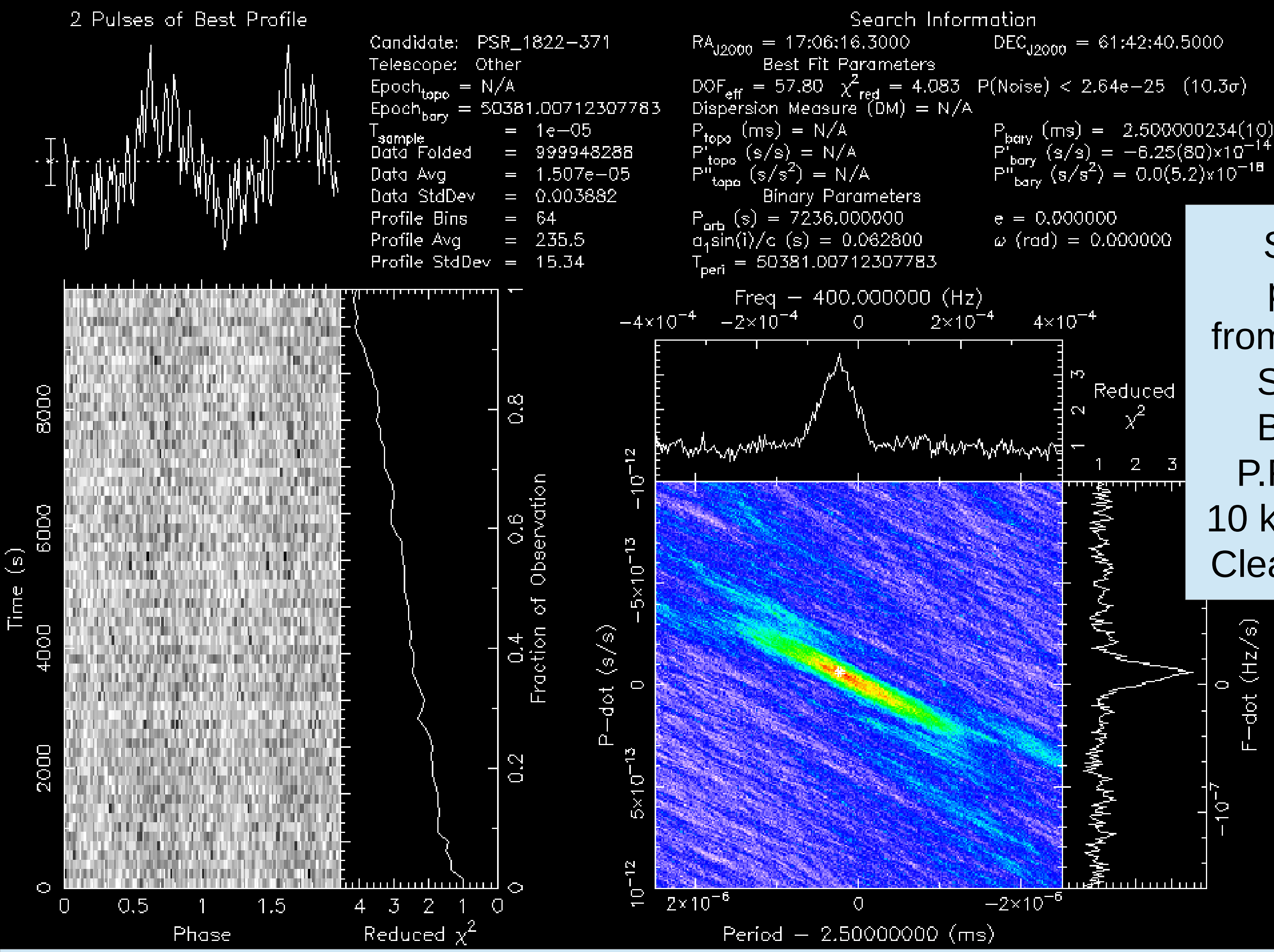
Ushomirsky et al. 2000
Haskell & Patruno 2017

Deep Pulse Search in LMXBs (in quiescence)

If we take a worse case scenario, with a quiescent LMXB of L~5e32 erg/s at the galactic center, then XRCA can see pulsations:

Amplitude ~4% rms
S/N = 5
Count rate: 1.5 ct/s
Bkg: 3.6 ct/s
Observing time: 10 ks

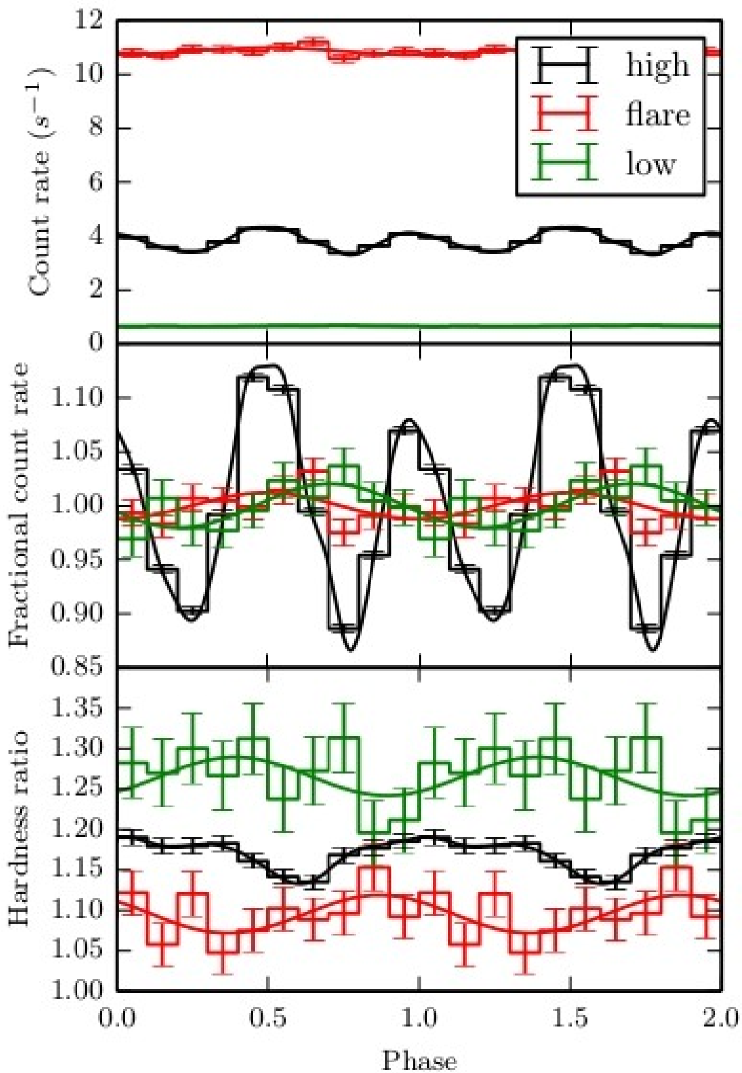
For L~5e33 the amplitude can go below 1% rms → possibility to detect pulsations in quiescence in many LMXBs (assuming they behave like the tMSPs).

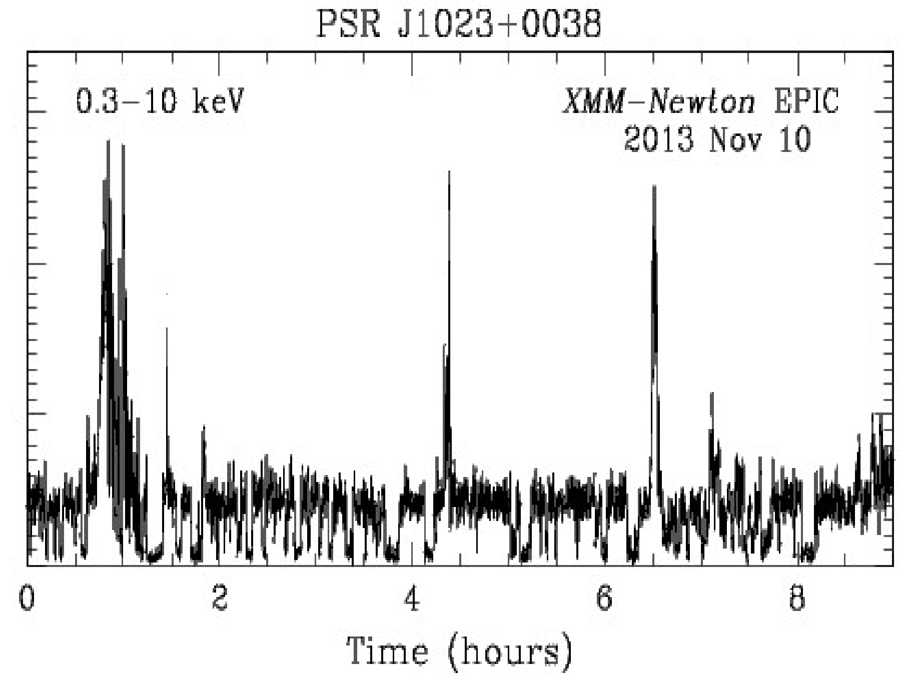


Simulated pulsations from faint source
S = 1.5 ct/s
B = 3.6 ct/s
P.F. = 7% rms
10 ks with XRCA
Clearly detected!

Cautionary words: to find these pulses you need some semi-coherent search since they are invisible in a simple power spectrum. Even acceleration searches can fail (if orbit is too short).

Evidence for pulsations in faint LMXBs



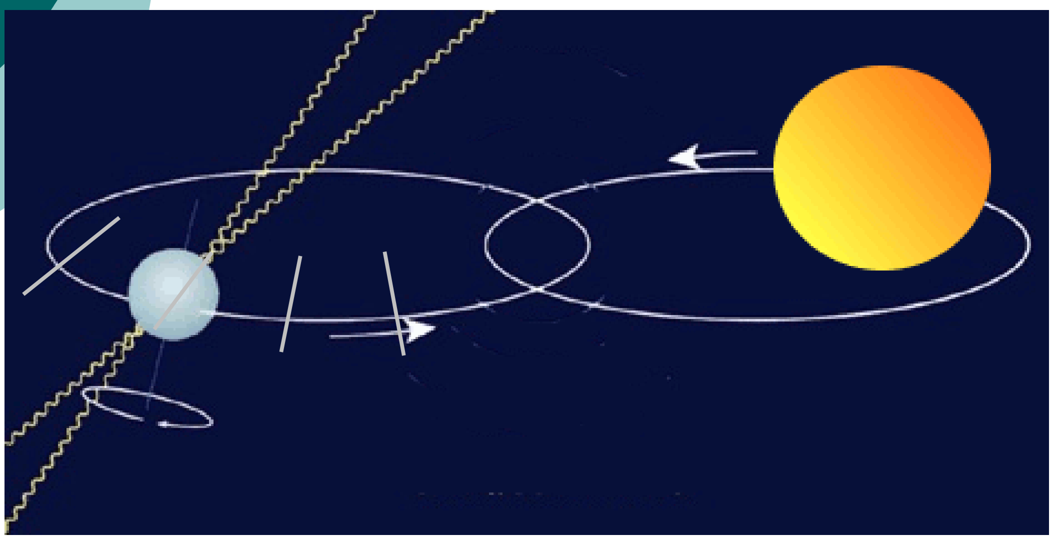


Intermittent Pulses!

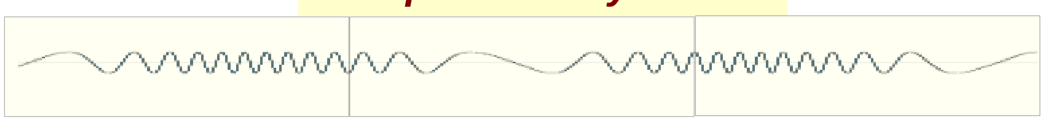
Archibald+ '15

Deep Pulse Search in LMXBs (in outburst)

(Patruno, Messenger & Wette 2017, Messenger & Patruno 2015)



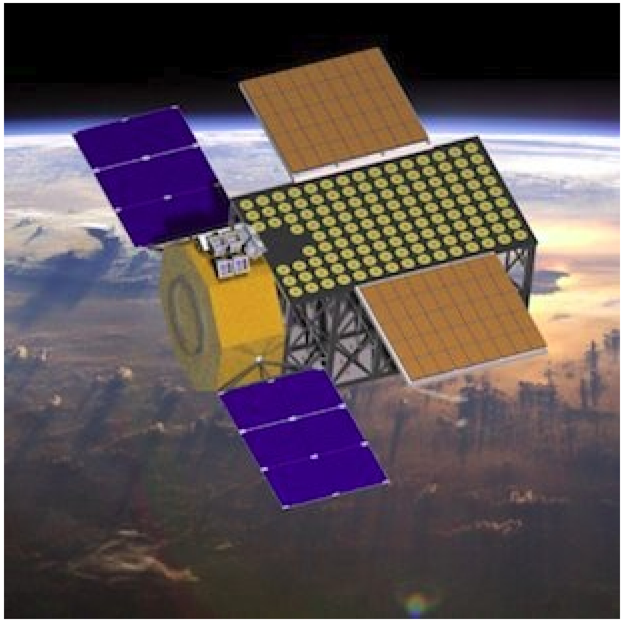
Computationally Bound



Name	UL	Orb. Period (hours)
4U 1636-53	<0.17%	4
4U 1735-44	<0.14%	5
XTE J2123-058	<0.34%	6
4U 1608-52	<0.18%	13
4U 2129+12	<0.35%	17
Aql X-1	<0.27%	19
4U 1543-475	<0.63%	27

Upper Limits → 1% false alarm
10% false dismissal

STROBE-X: Deep Pulse Search in LMXBs (in outburst)



Using XRCA (or LAD for harder sources) improves the sensitivity by about 1 order of magnitude.

LAD is superior to XRCA when the source is relatively hard (i.e., for most LMXBs).

Example:
Sensitivity of 4U 1608-52

XRCA	LAD
<0.07%	<0.03%

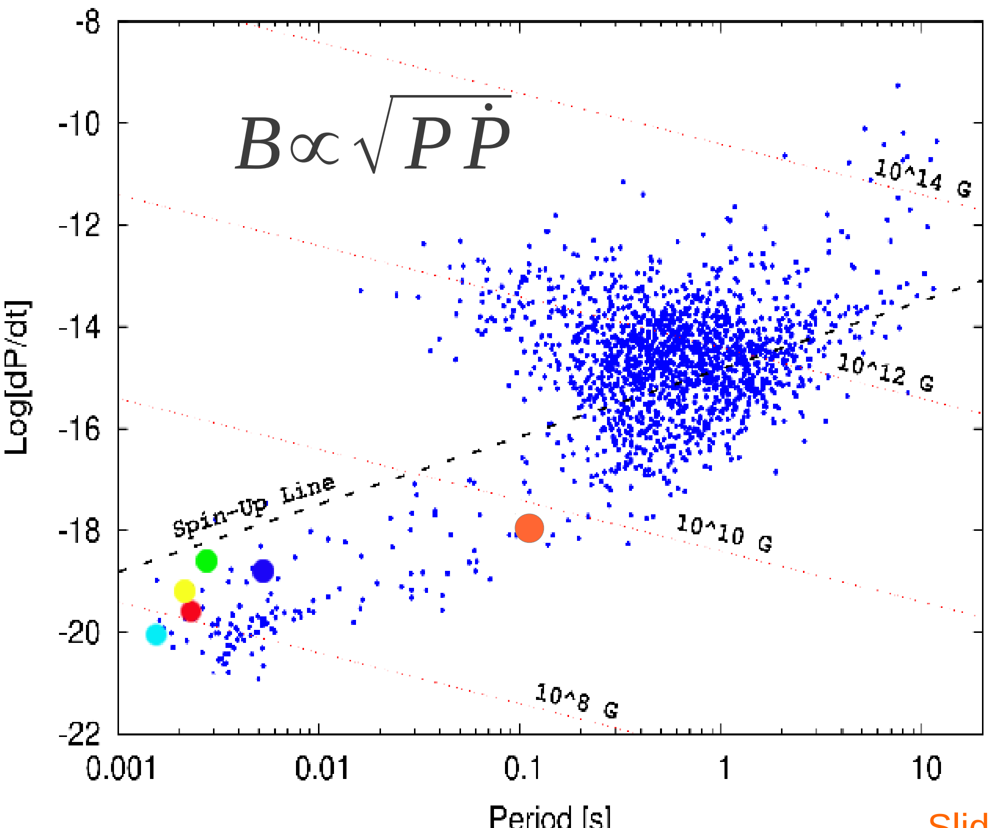
(based on XSPEC simulations and observation taken during the OB decay. From Armas-Padilla et al. 2017)

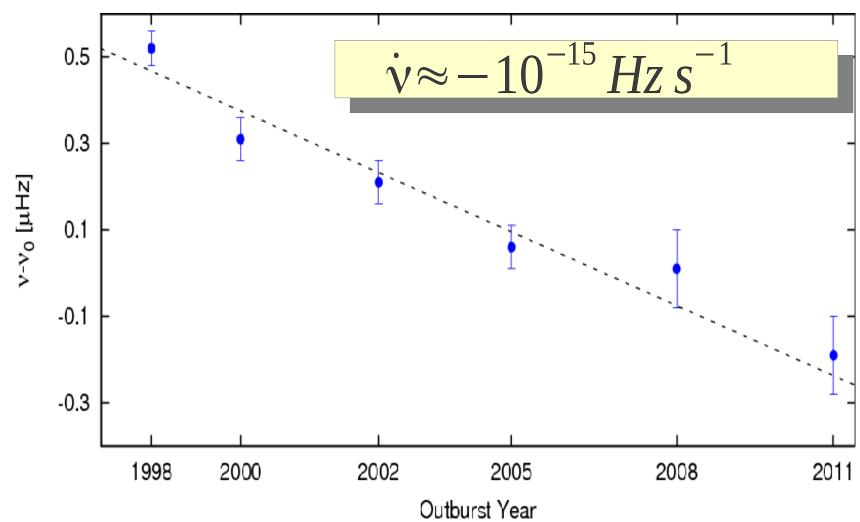
XRCA + LAD → improvement by a factor ~2 wrt XRCA or LAD alone

Spin Evolution of Accreting Pulsars

Today we need years to find a credible spin frequency derivative
STROBE-X can make this measurement in <1 day (but beware of timing noise)

$$\dot{\nu} \approx \sigma_{rms} / (\Delta t)^2$$

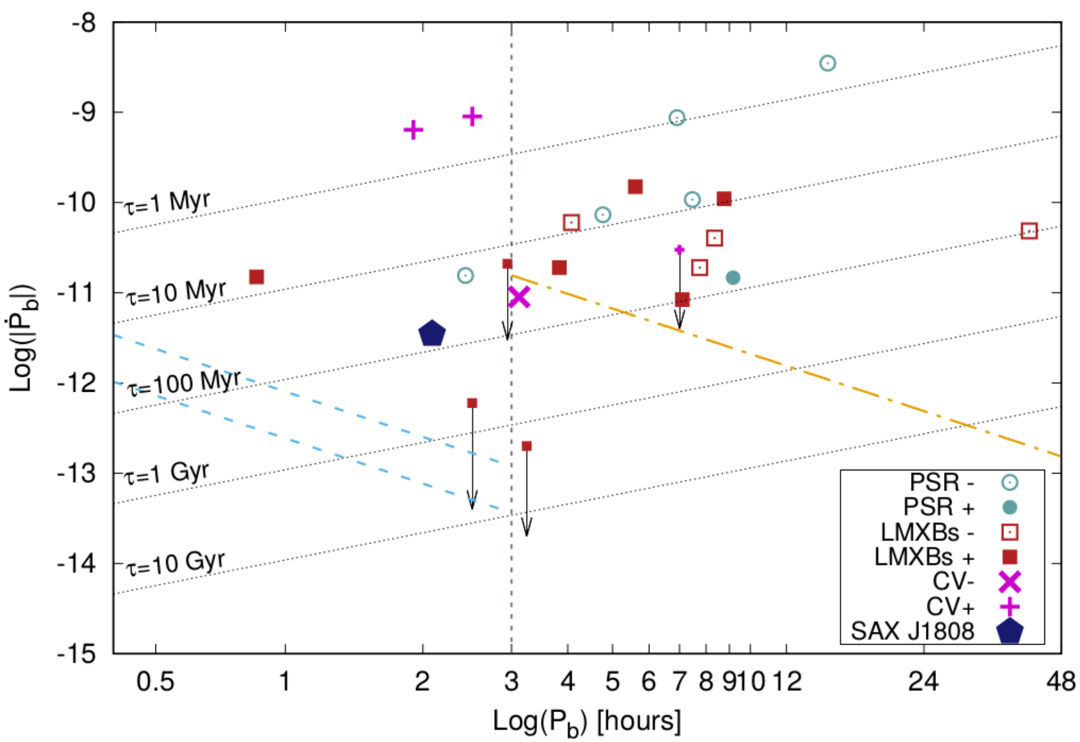




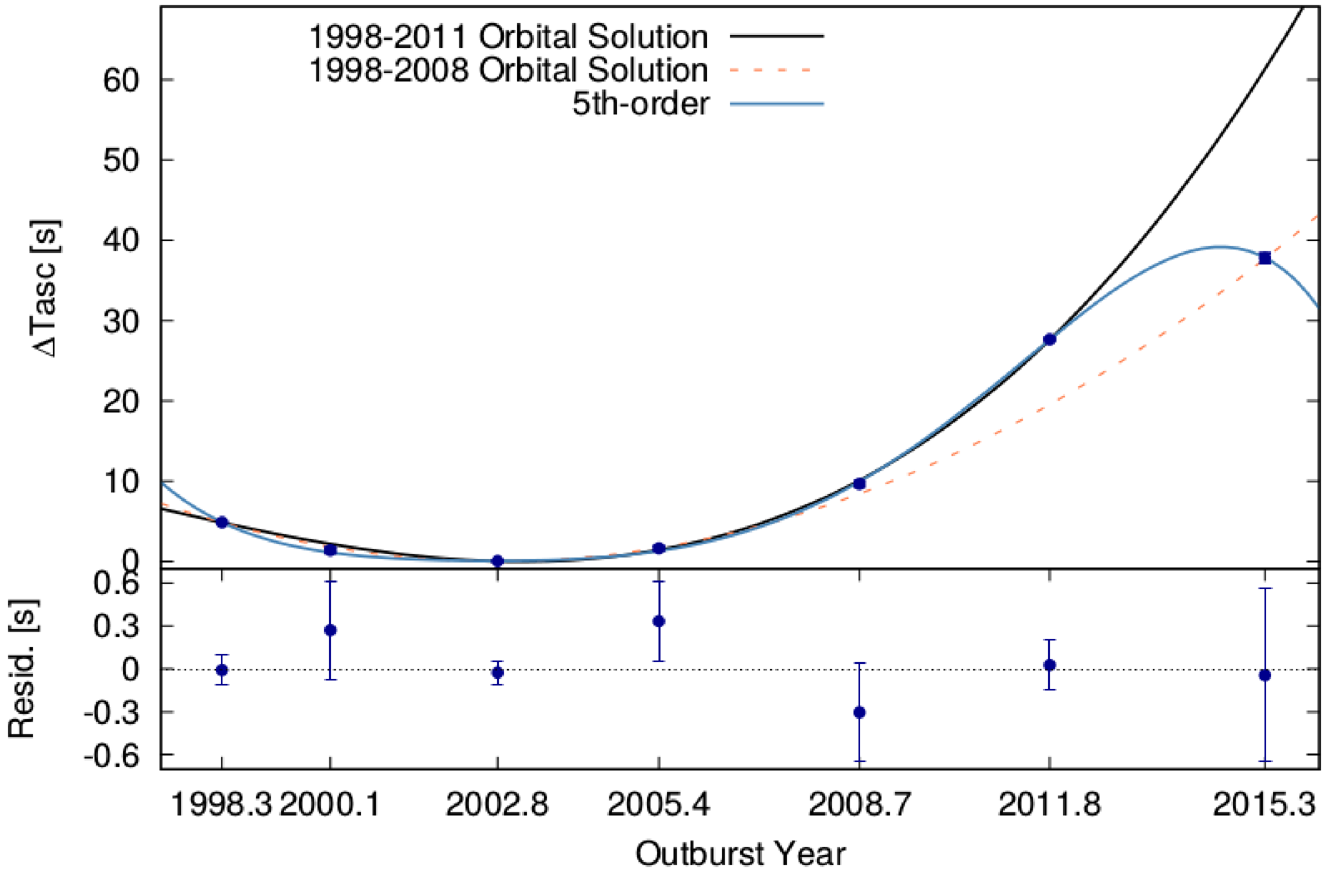
$$B = 3.2 \times 10^{19} \sqrt{\dot{\nu} / \nu^3}\, G$$

Orbital Evolution

Here the large area of STROBE-X can be of little help because the timescales of the orbital variation are dictated by physical processes and are not limited by counting statistics.
However, short timescale Pb_dots might be measurable, as well as xdot.



Orbital Evolution II



Now limited to outbursts, if STROBE-X can see pulses in quiescence one might reduce this interval substantially.

Summary of STROBE-X Capabilities

XRCA → exceptional for faint/quiescent LMXBs.
Can unlock new type of science:
- pulsations in quiescent accreting NS (not possible today)
- spin evolution in quiescence on timescales of days (now it’s years)
- detection of spin variations due to effects now visible today (e.g. gravitational waves, propeller in quiescence, etc.)
- orbital evolution on a continuous time interval.

LAD → excellent for outbursting sources, but it provides a substantially better performance only for relatively hard sources (which, however, are abundant)

Spectral capabilities do not affect these type of studies in any way.