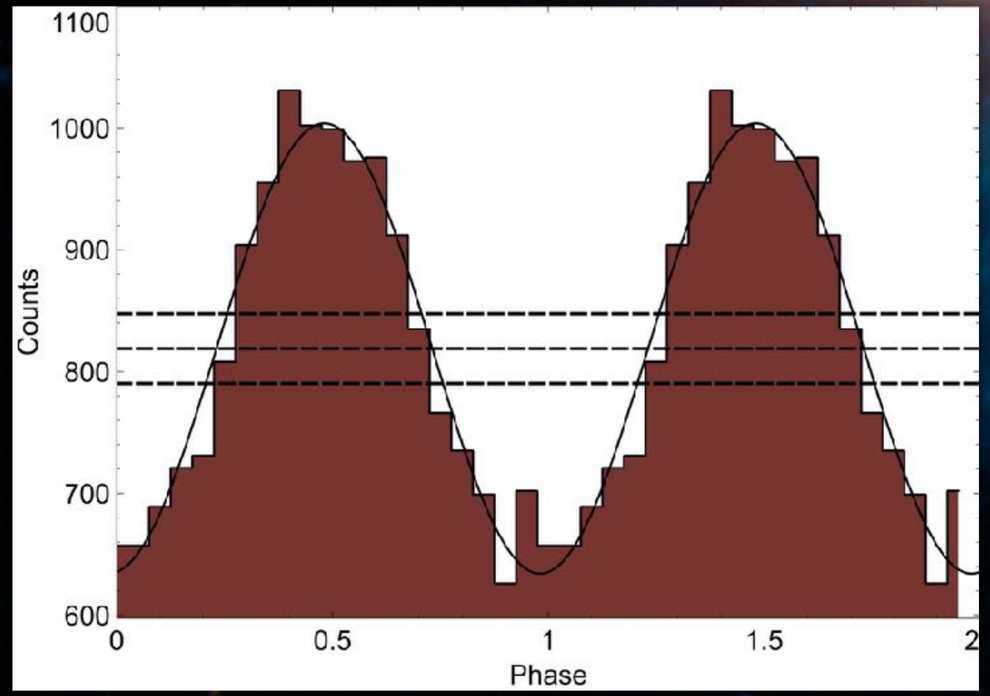
Timing PULXs

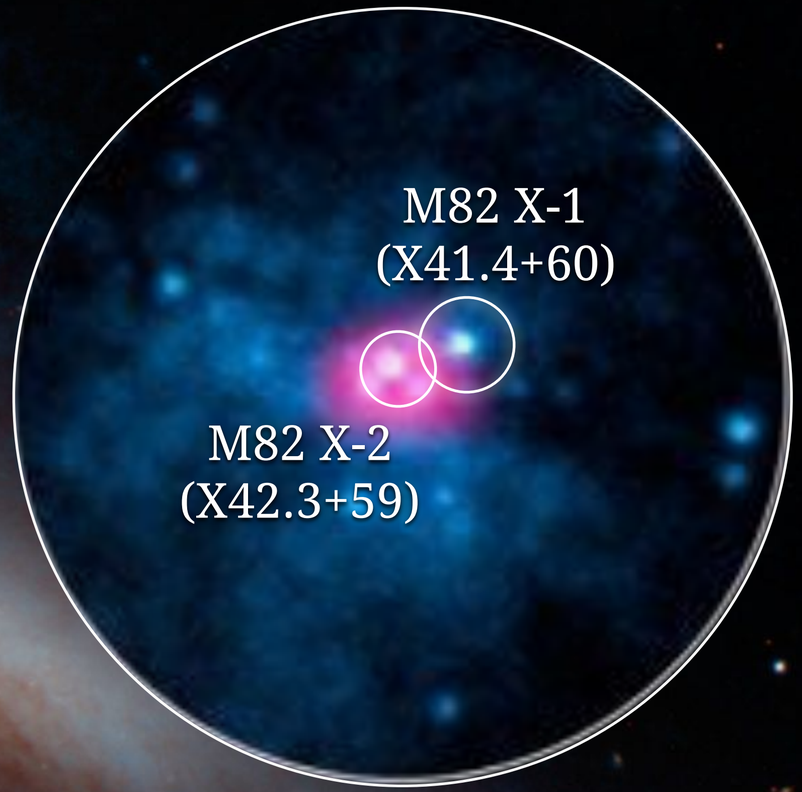
Matteo Bachetti

with

F. Fürst, B. Grefenstette, D. Walton, G. Israel, G. Rodriguez, M. Brumback, S. Pike, J. Kennea,
F. Harrison, M. Middleton, M. Pilia, J. Tomsick, and more.

The beginning: M82 X-2

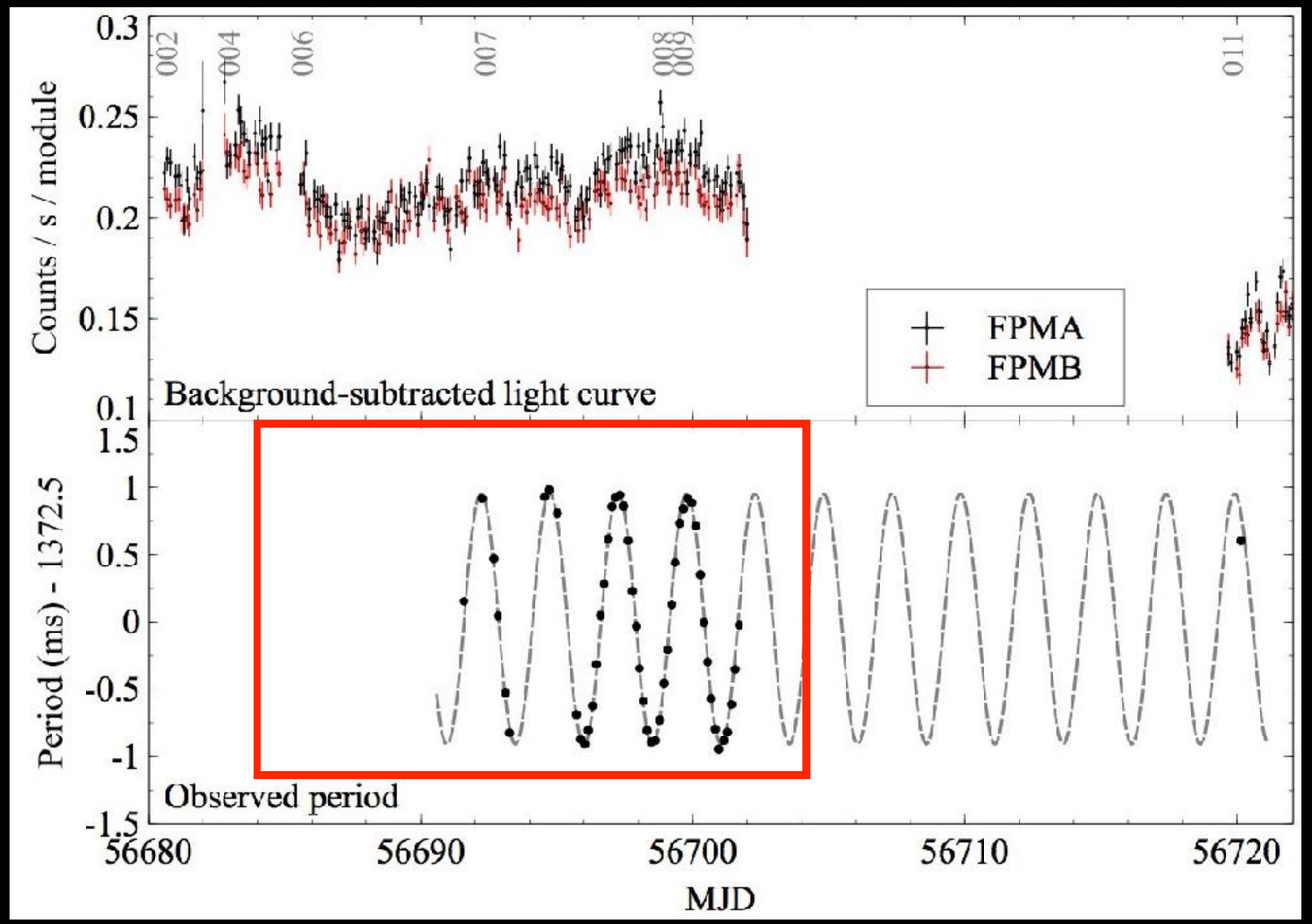




Bachetti +14, Nat.

Timing properties of M82 X-2

- Orbit immediately apparent - 2.54 d
- Hint of spin-up



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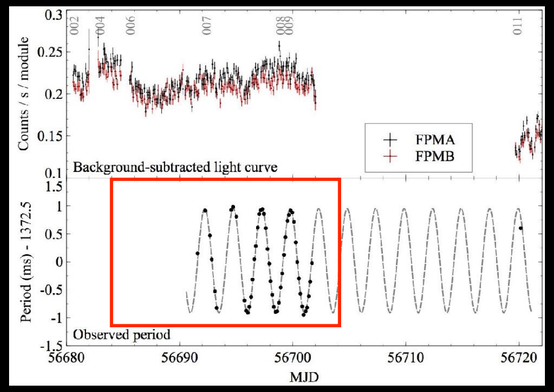
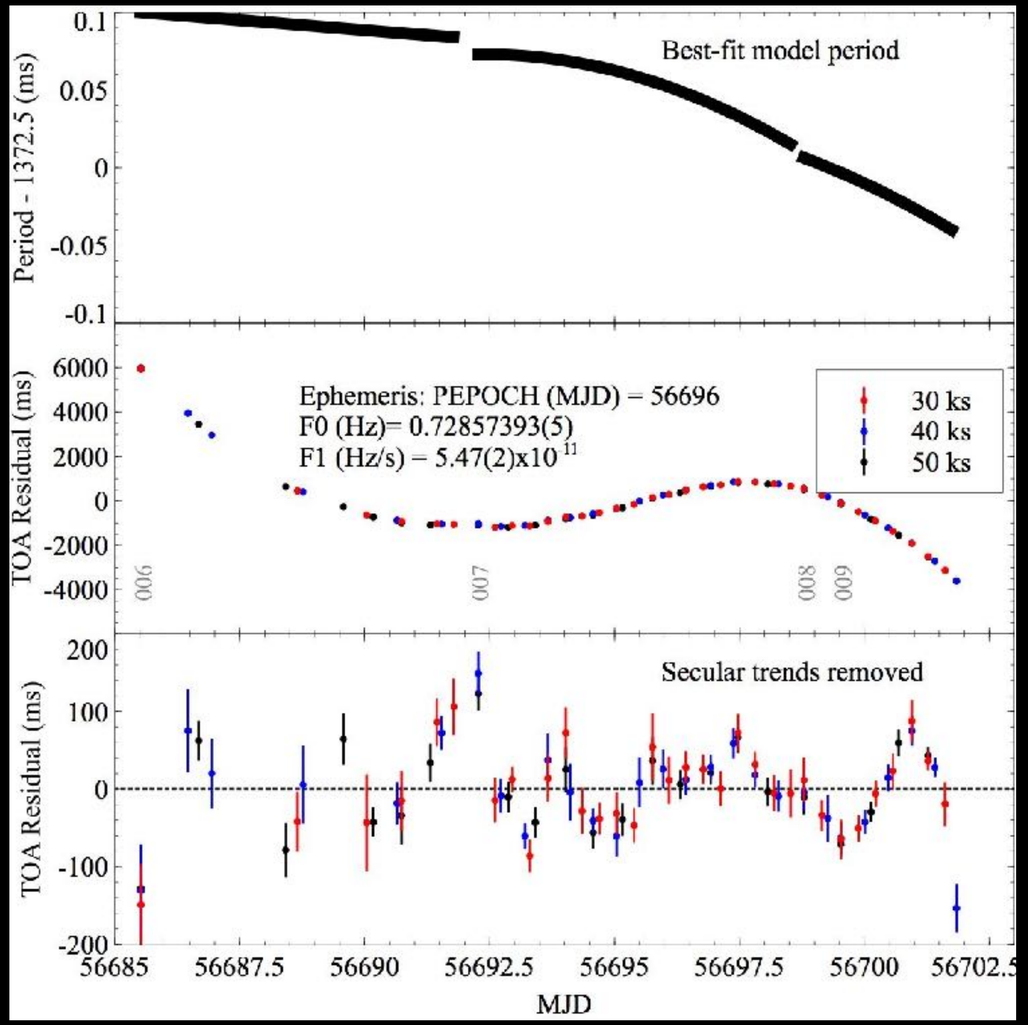


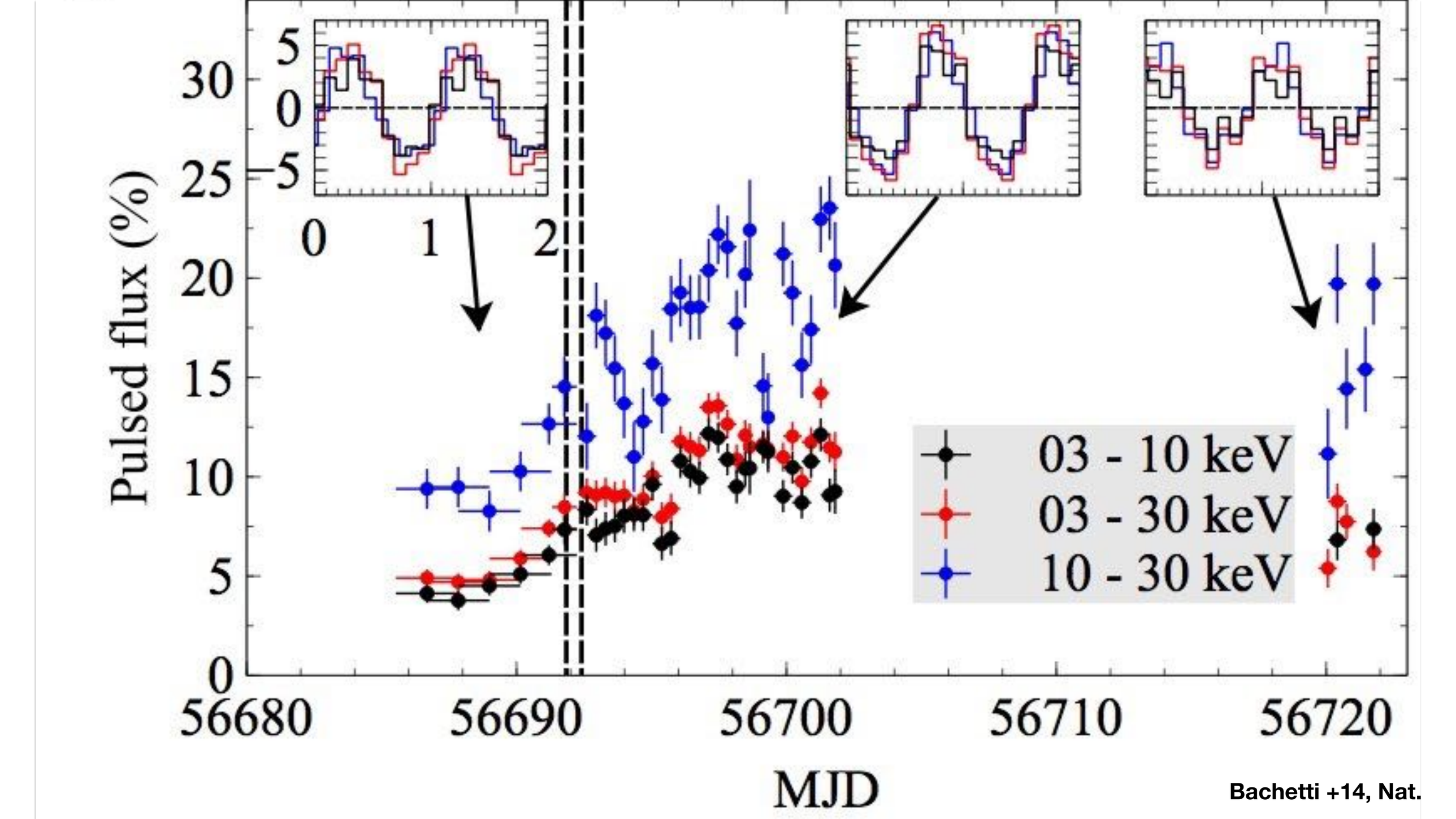
Bachetti +14, Nat.

Non-constant spin up

- Once orbit eliminated, clear spin up.
- Once *constant* spin up eliminated, additional (erratic?) spin variations



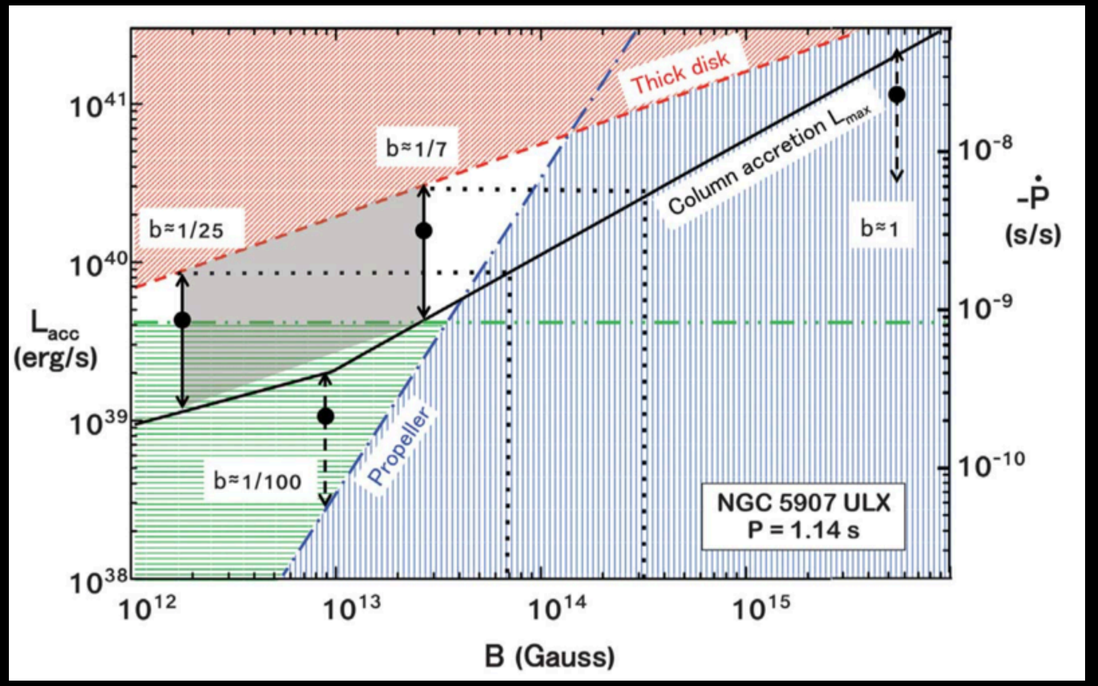
Bachetti +14, Nat.



Bachetti +14, Nat.

NGC 5907

- The most luminous PULX known
- Difficult to reconcile with existing models of magnetic torque
- Strongest frequency derivative
- No orbit detected.

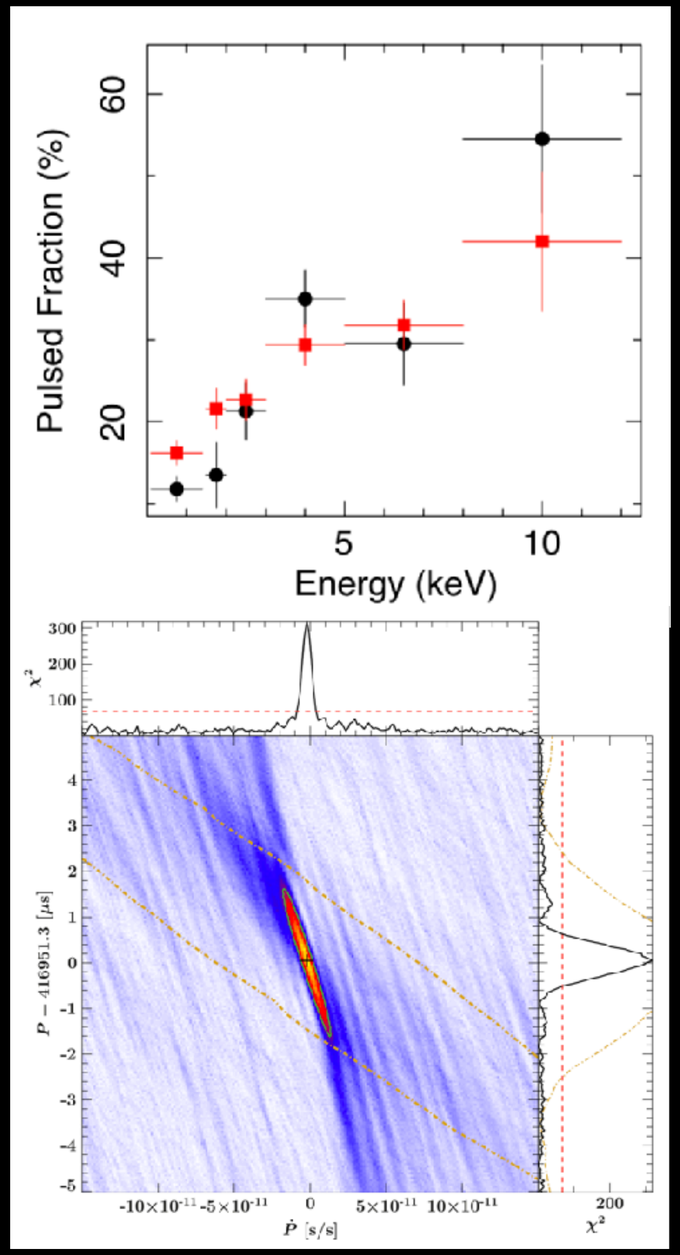


Start date	2003 Feb 28	2014 Jul 09	2014 Jul 09	2014 Jul 12
Mission	XMM-Newton	NuSTAR	XMM-Newton	NuSTAR
Epoch (MJD)	52,690.9	56,848.0	56,848.2	56,851.5
P (s)	1.427579(5)	1.137403(1)	1.137316(3)	1.136042(1)
$\dot{P}$ (10^{-9} s s^{-1})	−9.6(9)	−5.2(1)	−5.0(5)	−4.7(1)

Israel +17, Sci.

NGC 7793

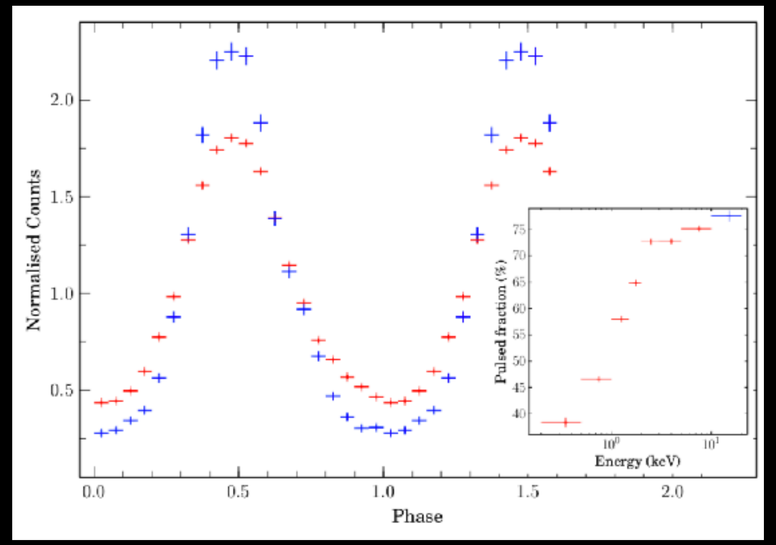
- Shortest period in a ULX: 0.4 s
- Small detectable spin up
- Possible orbit 64 d not visible from pulsar timing (face-on?)

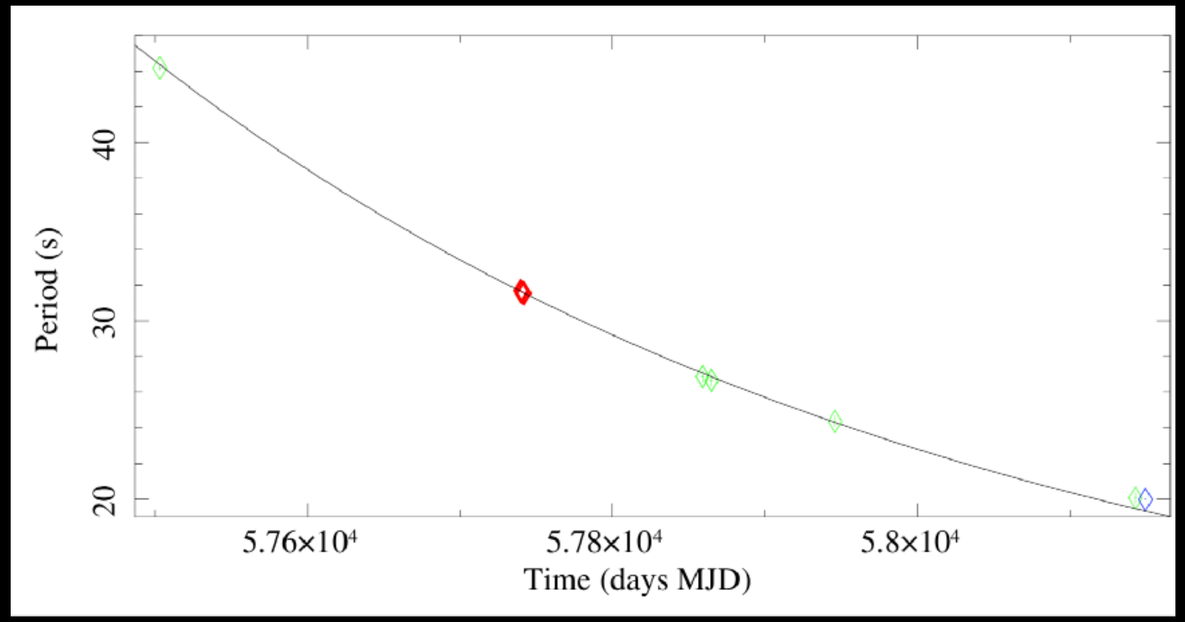


Israel +17, MNRAS; Fuerst +16, ApJ.

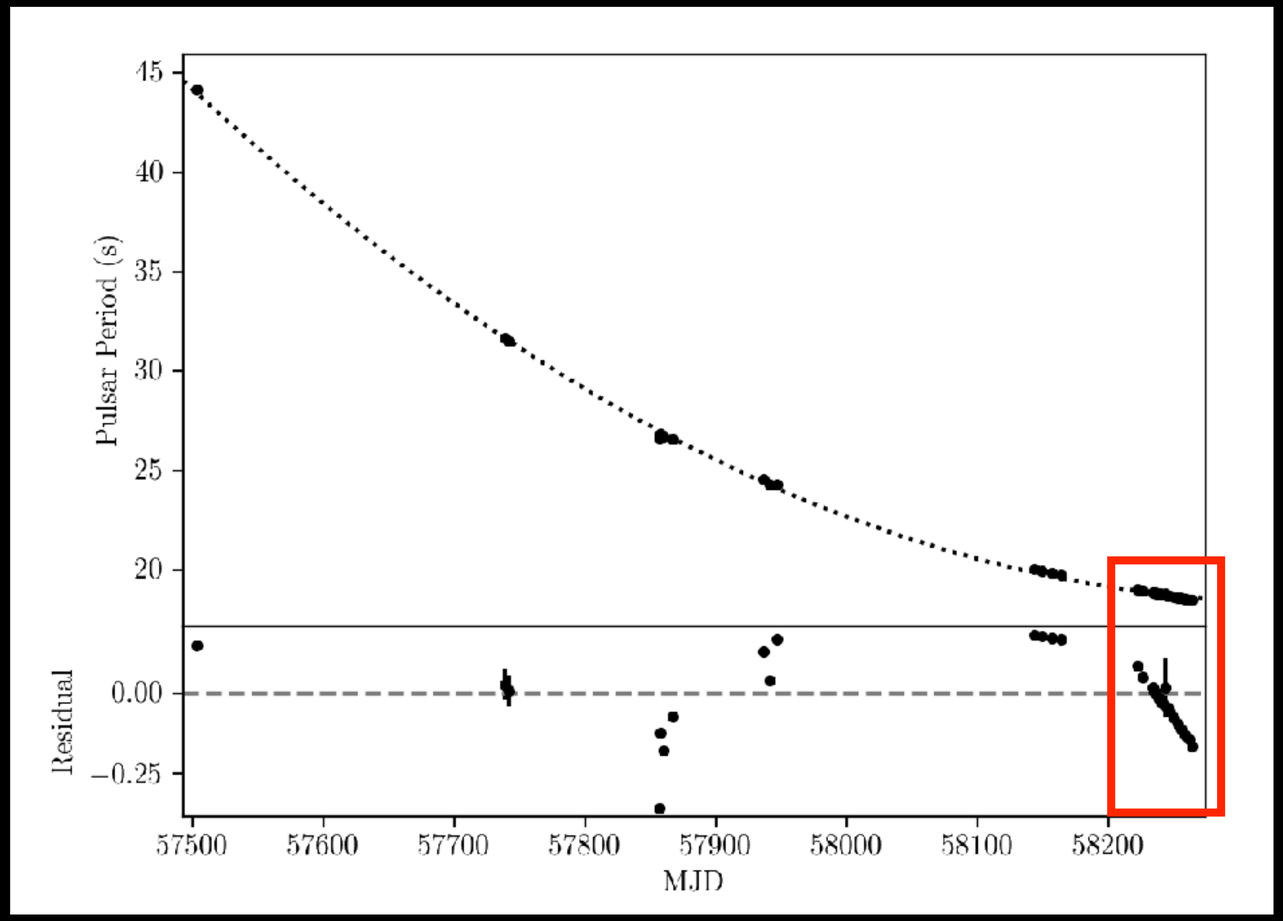
NGC 300

- Borderline ULX (5×10^{39} erg/s)
- Long period, strong spin up (10^{-7} s/s)
- Strong pulsed fraction (80% in NuSTAR band)

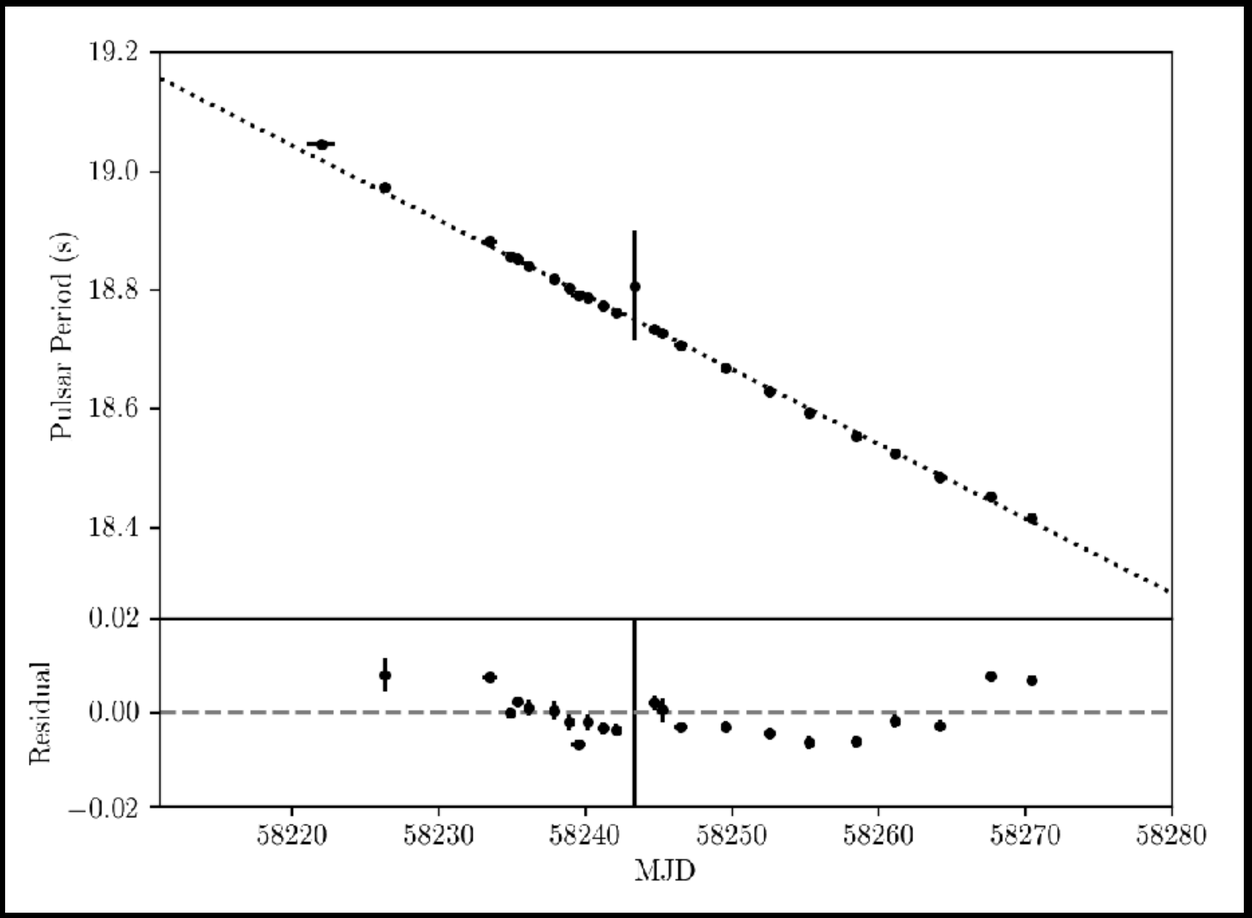


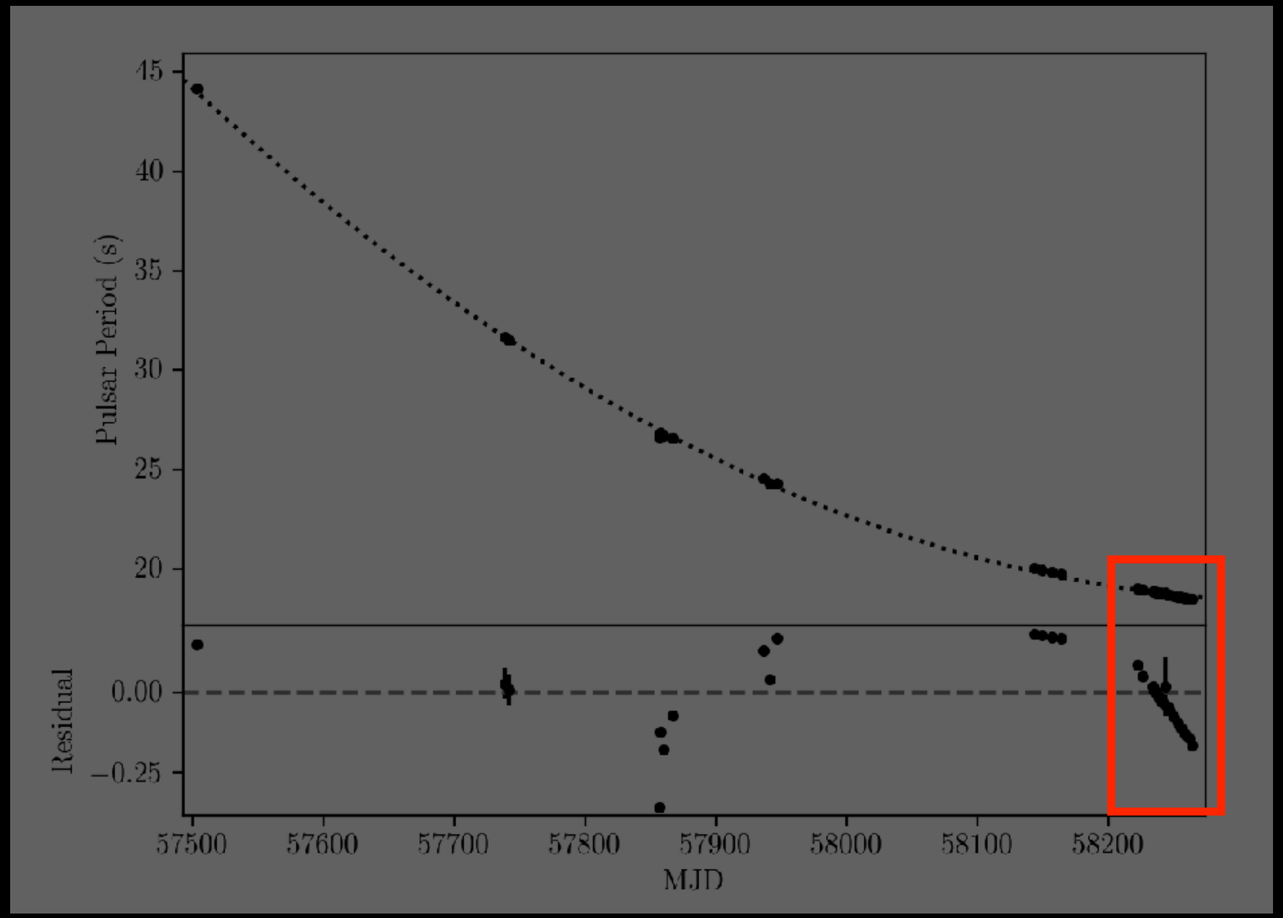


Carpano +18, MNRAS — see Haberl's talk



Courtesy J. Kennea





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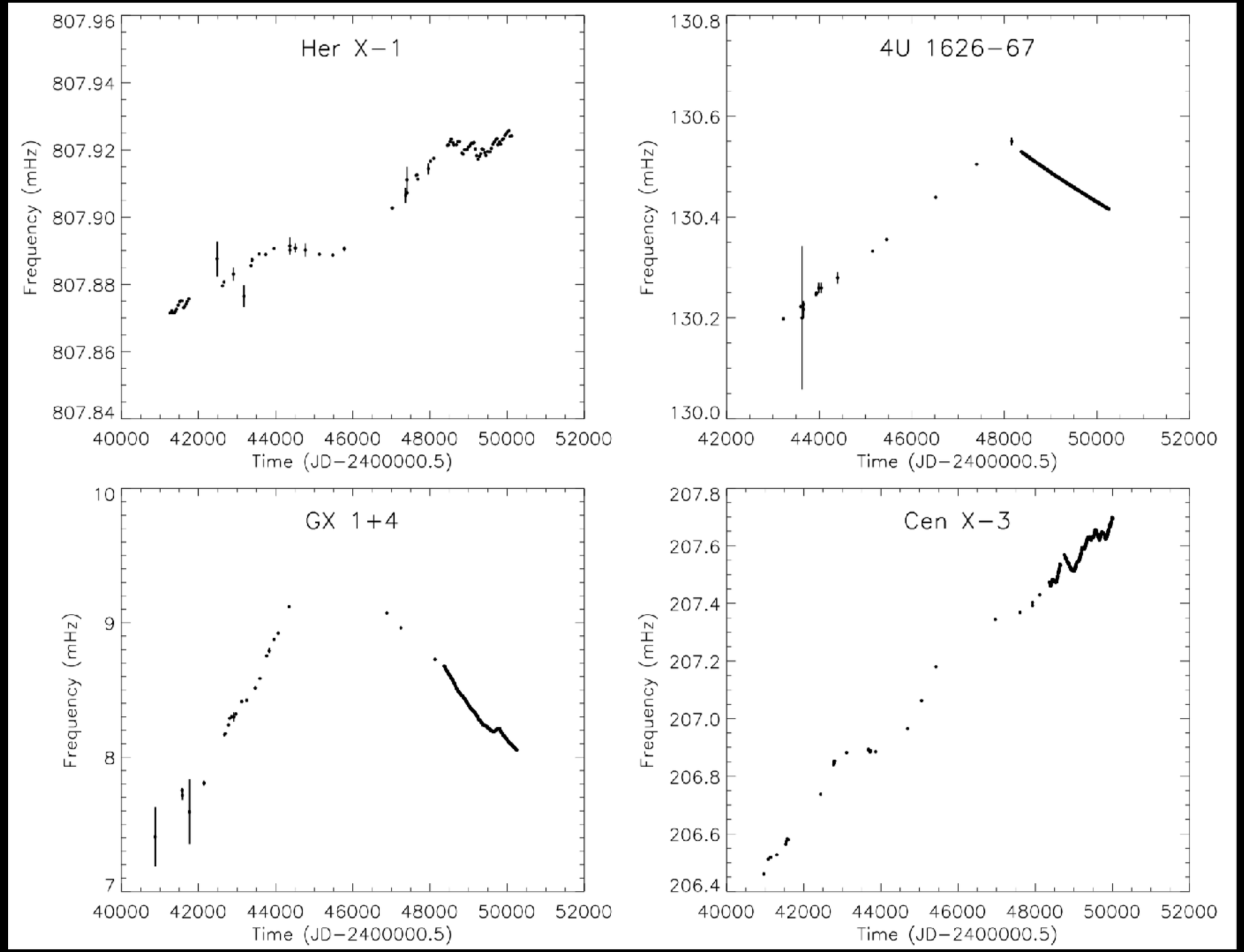

Her X−1
4U 1626−67
GX 1+4
Cen X−3
Frequency (mHz)
Time (JD−2400000.5)
807.96
807.94
807.92
807.90
807.88
807.86
807.84
130.8
130.6
130.4
130.2
130.0
10
9
8
7
207.8
207.6
207.4
207.2
207.0
206.8
206.6
206.4
40000
42000
44000
46000
48000
50000
52000

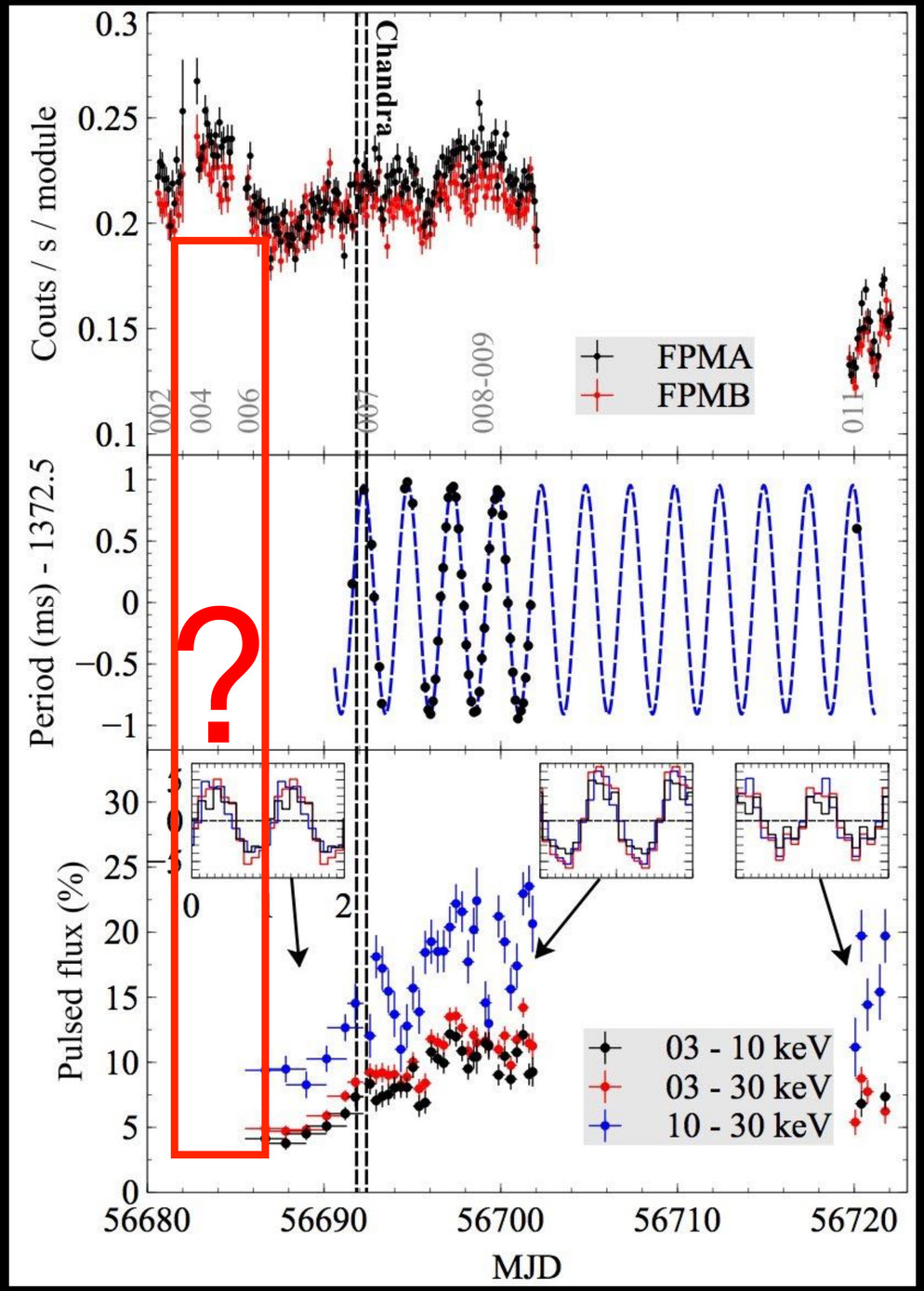
Bildsten +97

PULX table (and comparison)

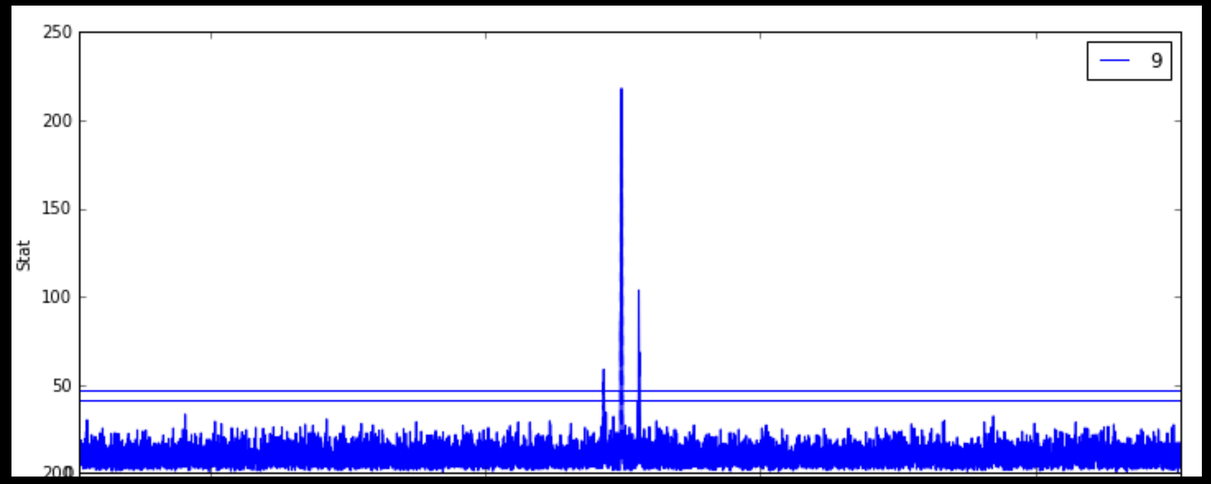
	f (Hz)	$\dot{f}$ (10^{-10} Hz/s)	P.F. (%)
M82 X-2	0.7	~1	>20
NGC 7793 P13	**2.4**	~2	~20
NGC 5907 X-1	0.7	**~57**	~15
	0.9	**~37**	~15
NGC 300 ULX	0.03	5.5	**~90**
	0.05	4.3	**~90**
SMC X-1	1.4	0.23	
LMC X-4	0.07	~1	

See talk by Brumback, posters by Townsend and Pike

Transient pulsations



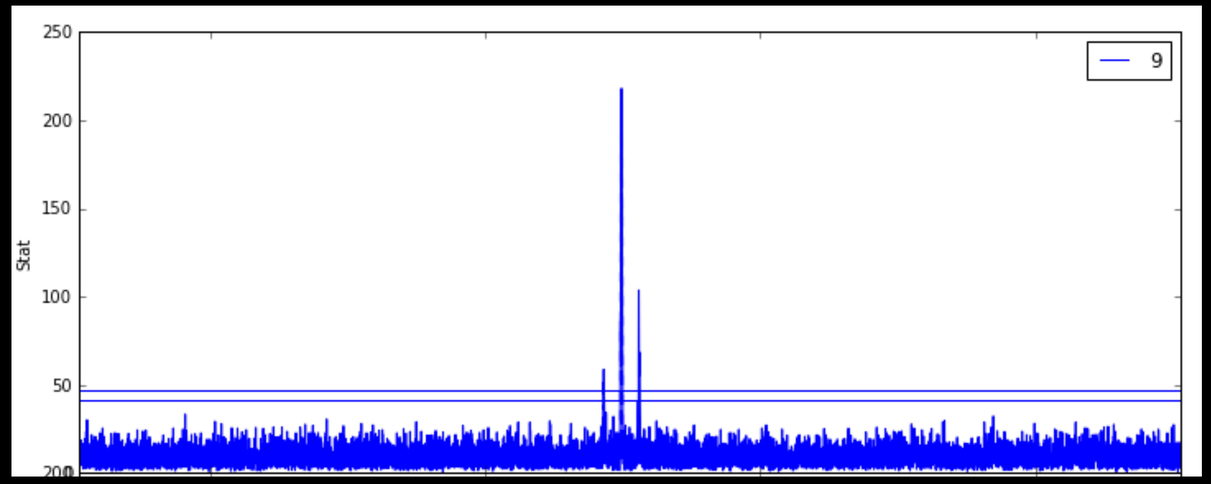
Stat ->



Pulse period ->

2014

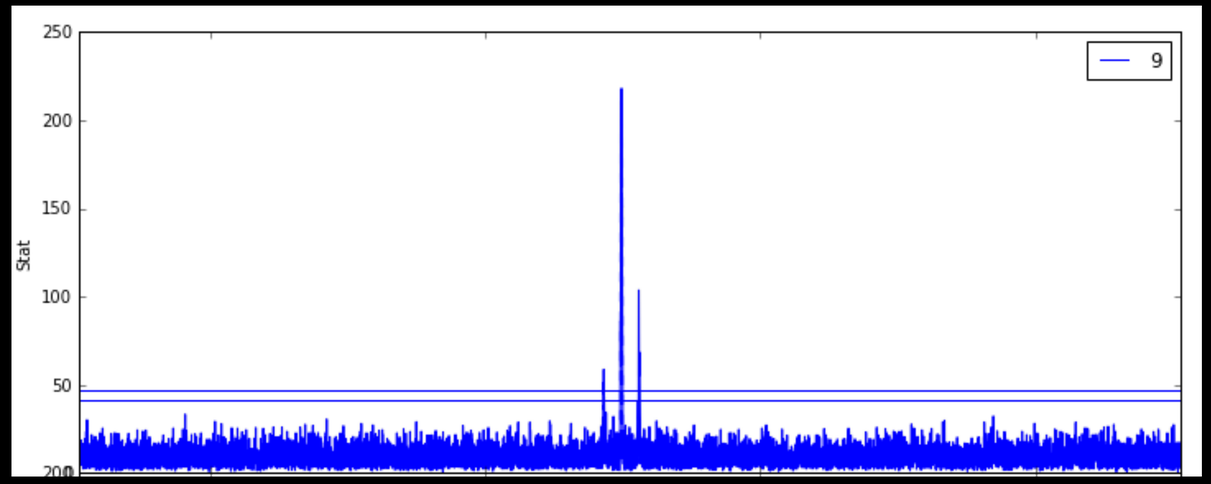
Stat ->



Pulse period ->

2014

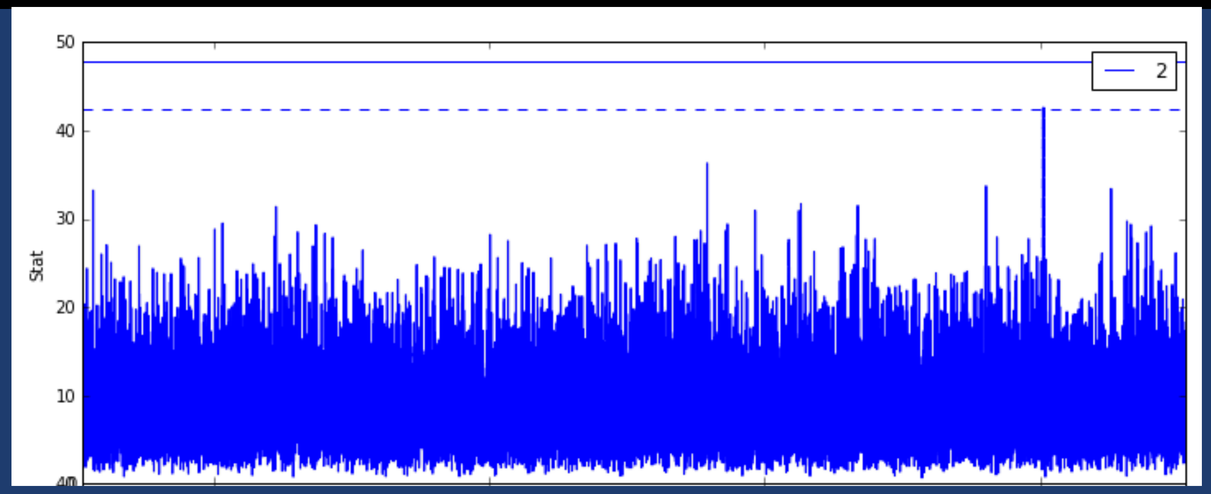
Stat ->



Pulse period ->

2014

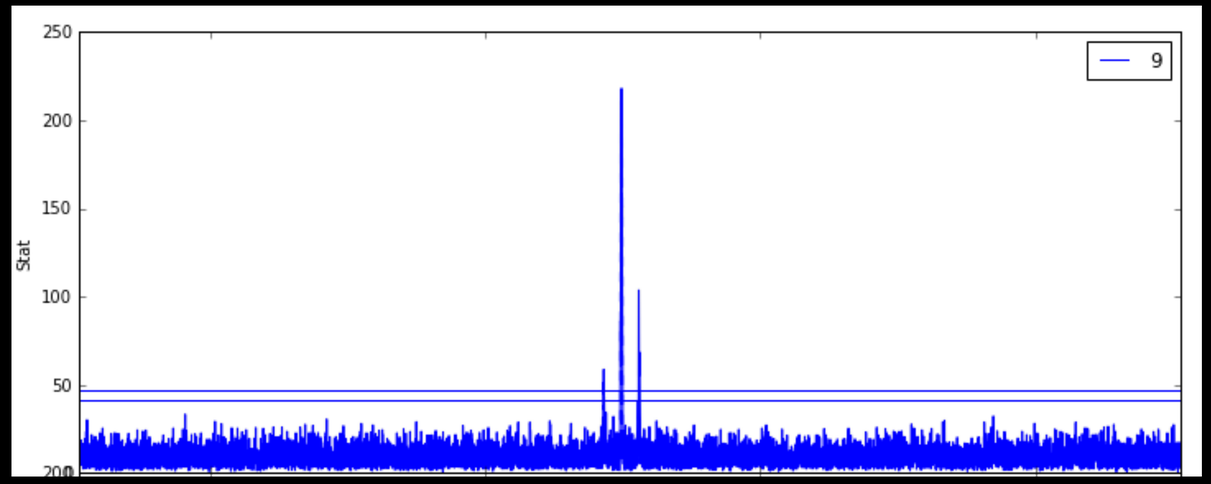
Stat ->



Pulse period ->

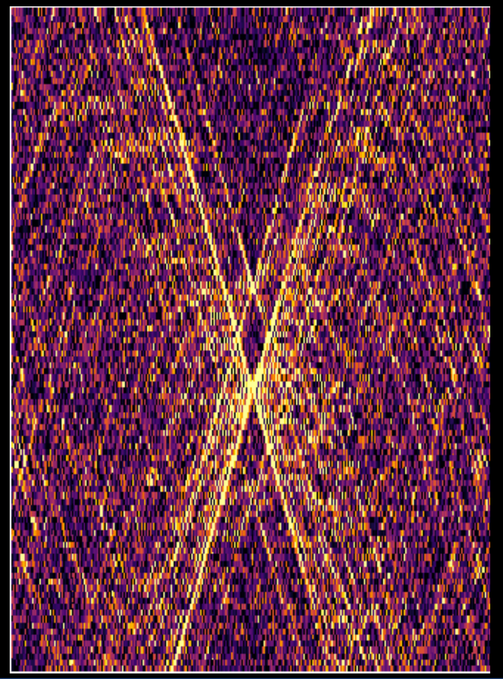
2016

Stat ->



Pulse period ->

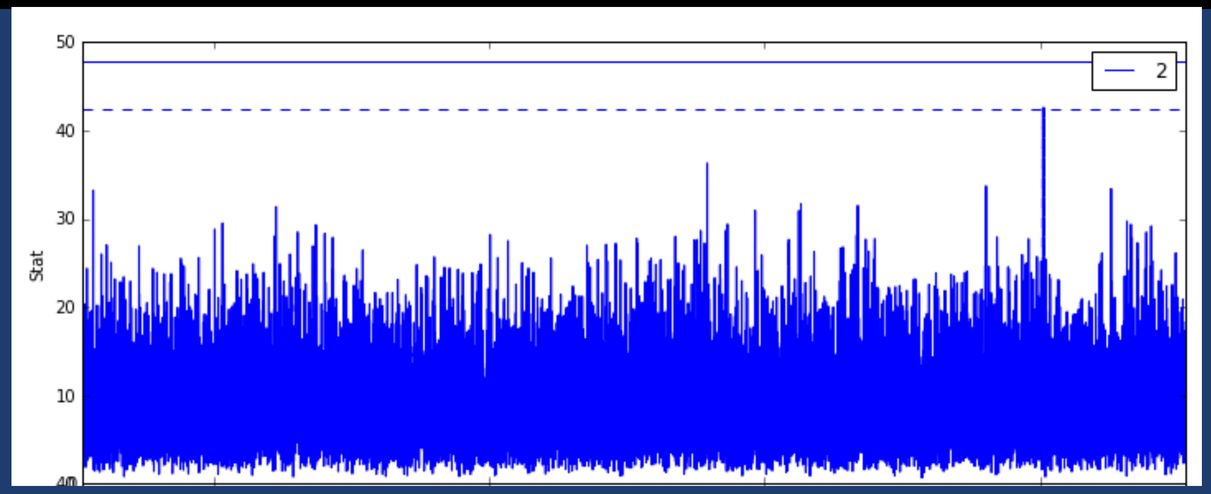
Pulse period ->



T_0 ->

2014

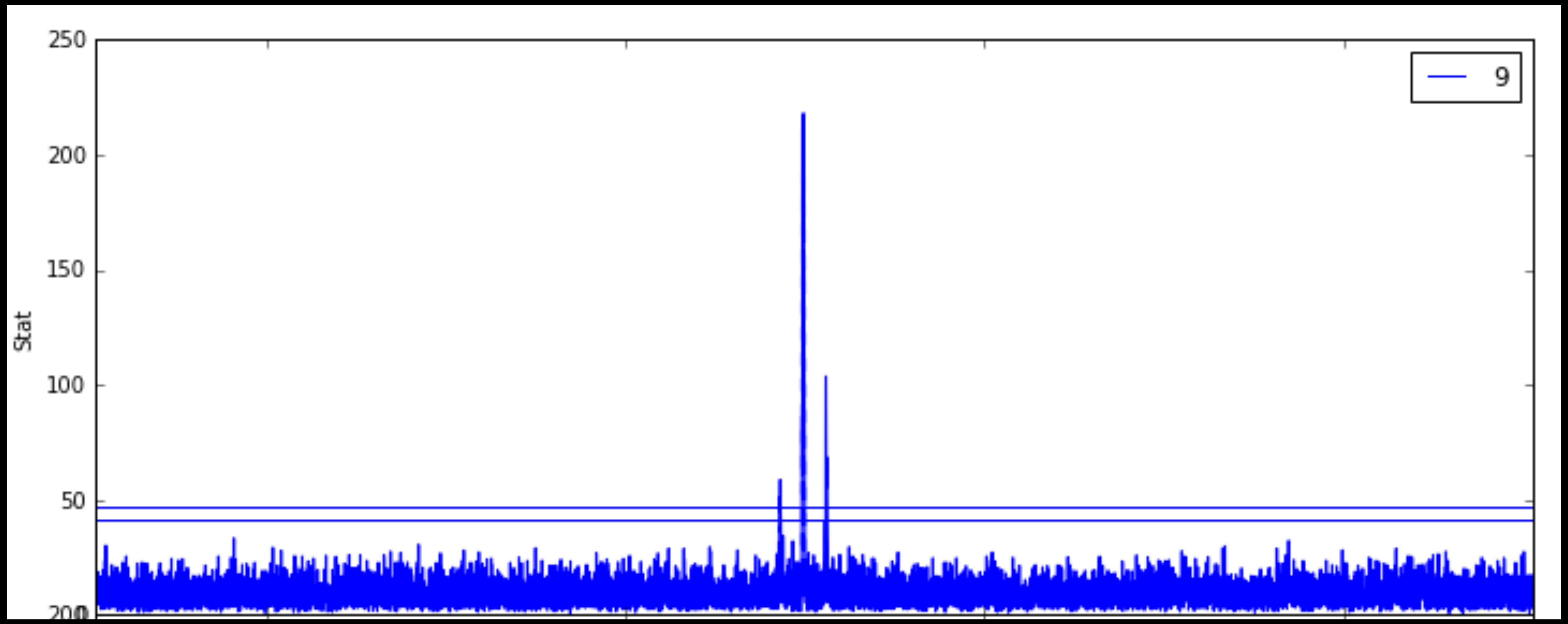
Stat ->



Pulse period ->

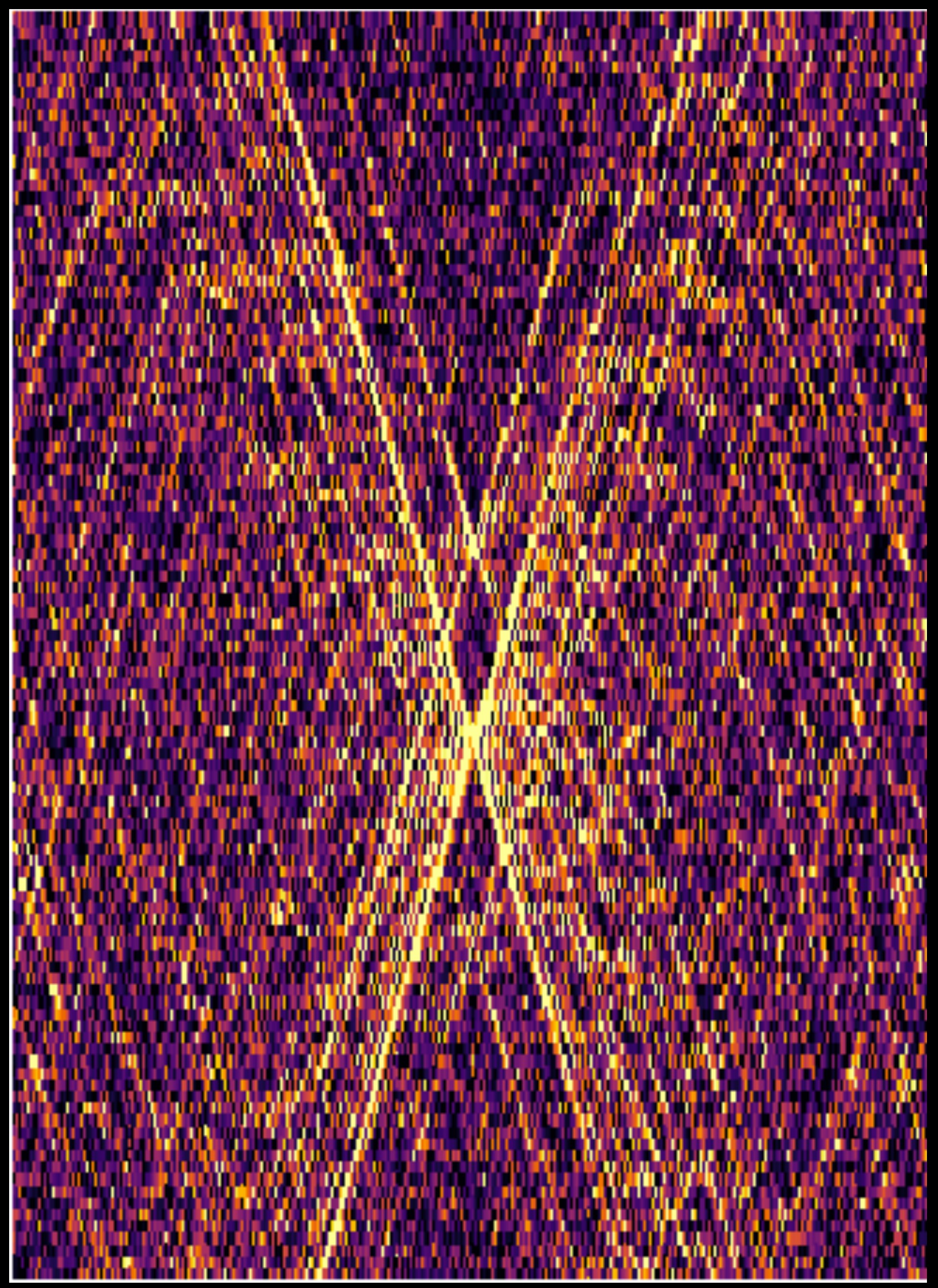
2016

Stat ->



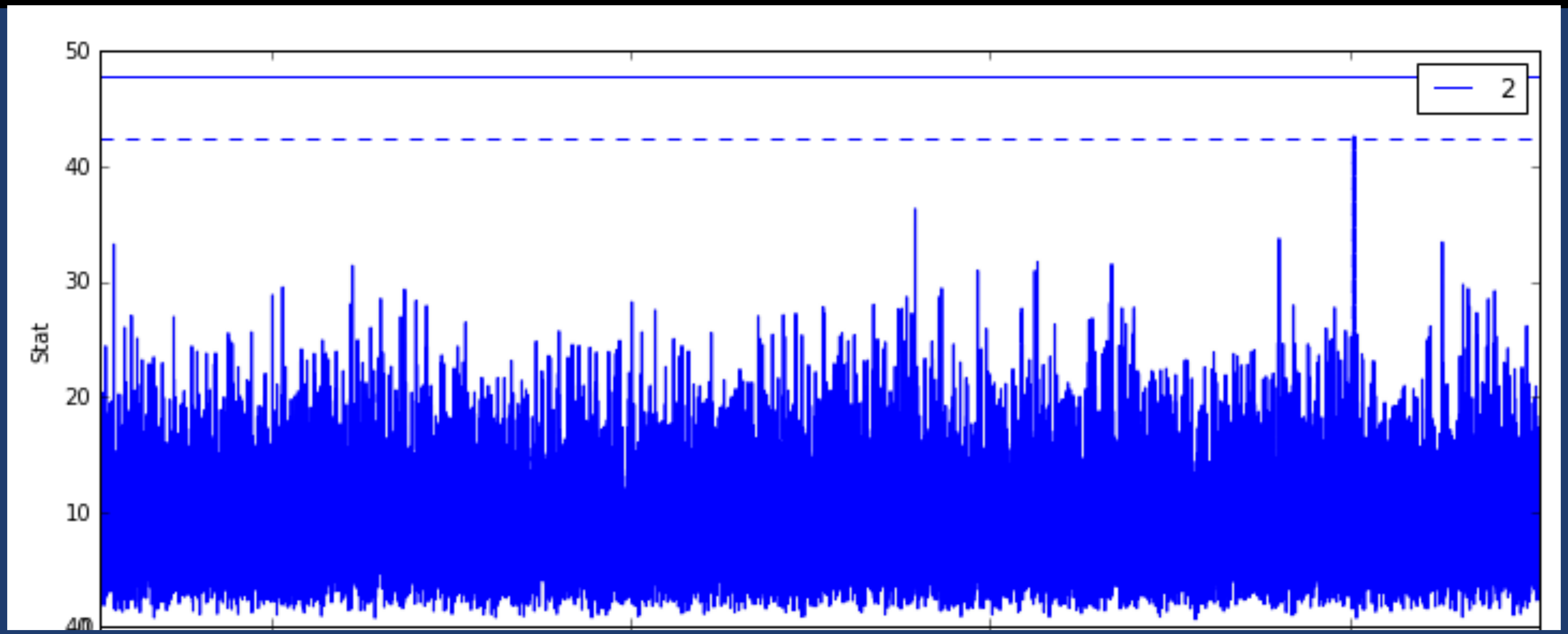
Pulse period ->

Pulse period ->

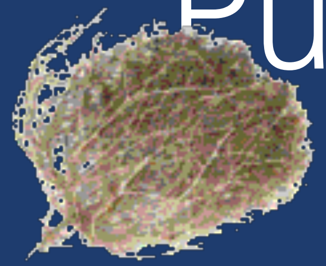


2014

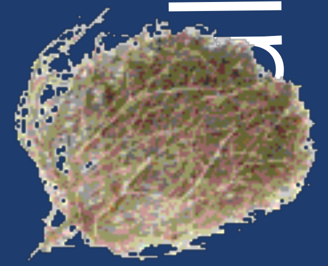
Stat ->

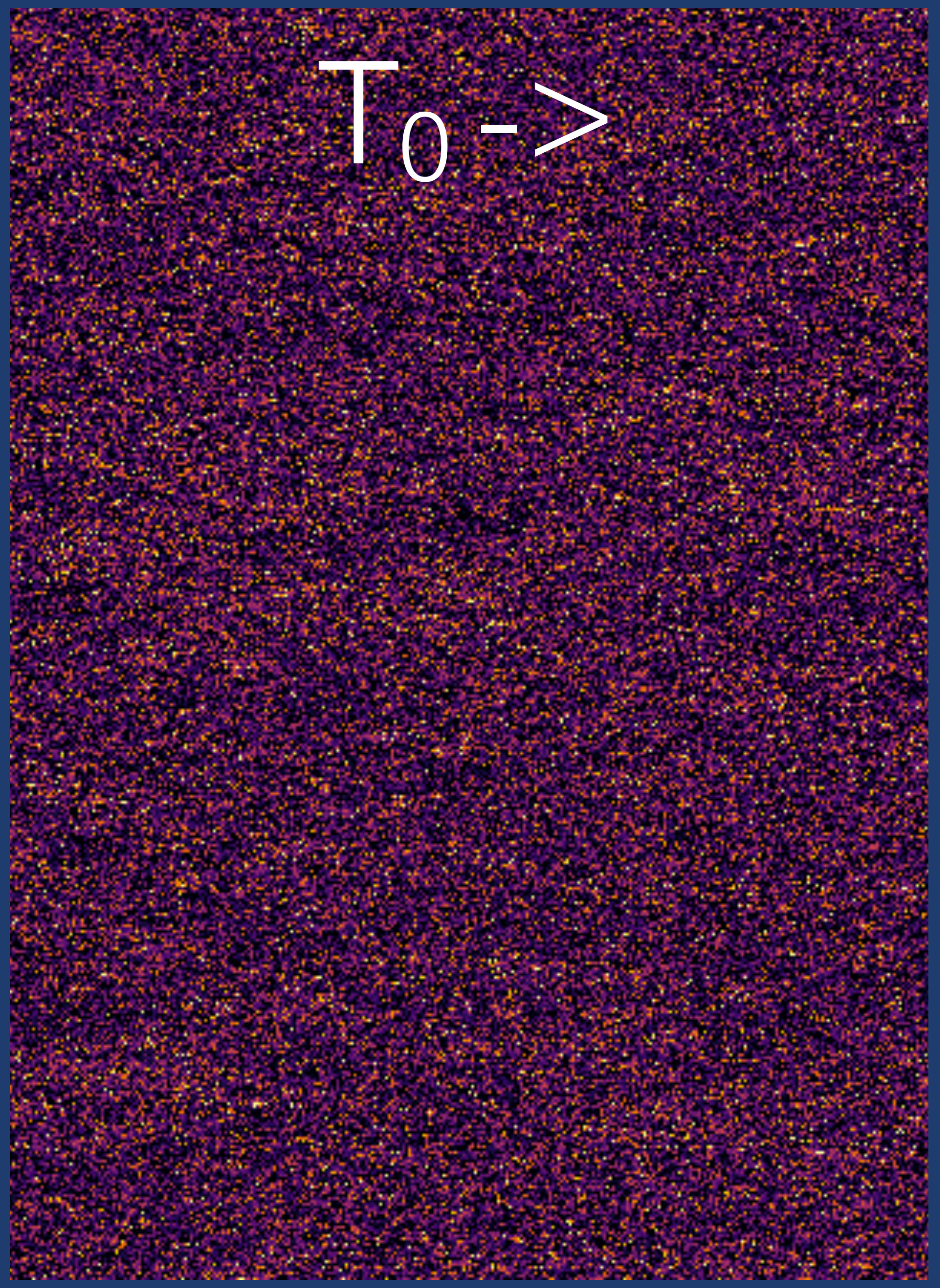


Pulse period ->



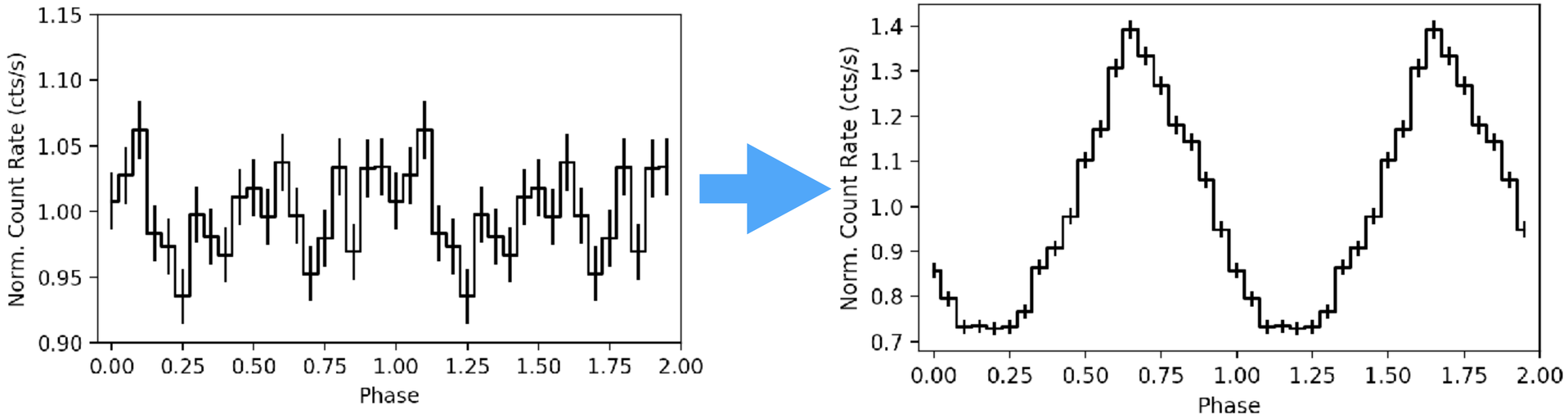
Pulse period ->





2016

Transient pulsations in LMC X-4



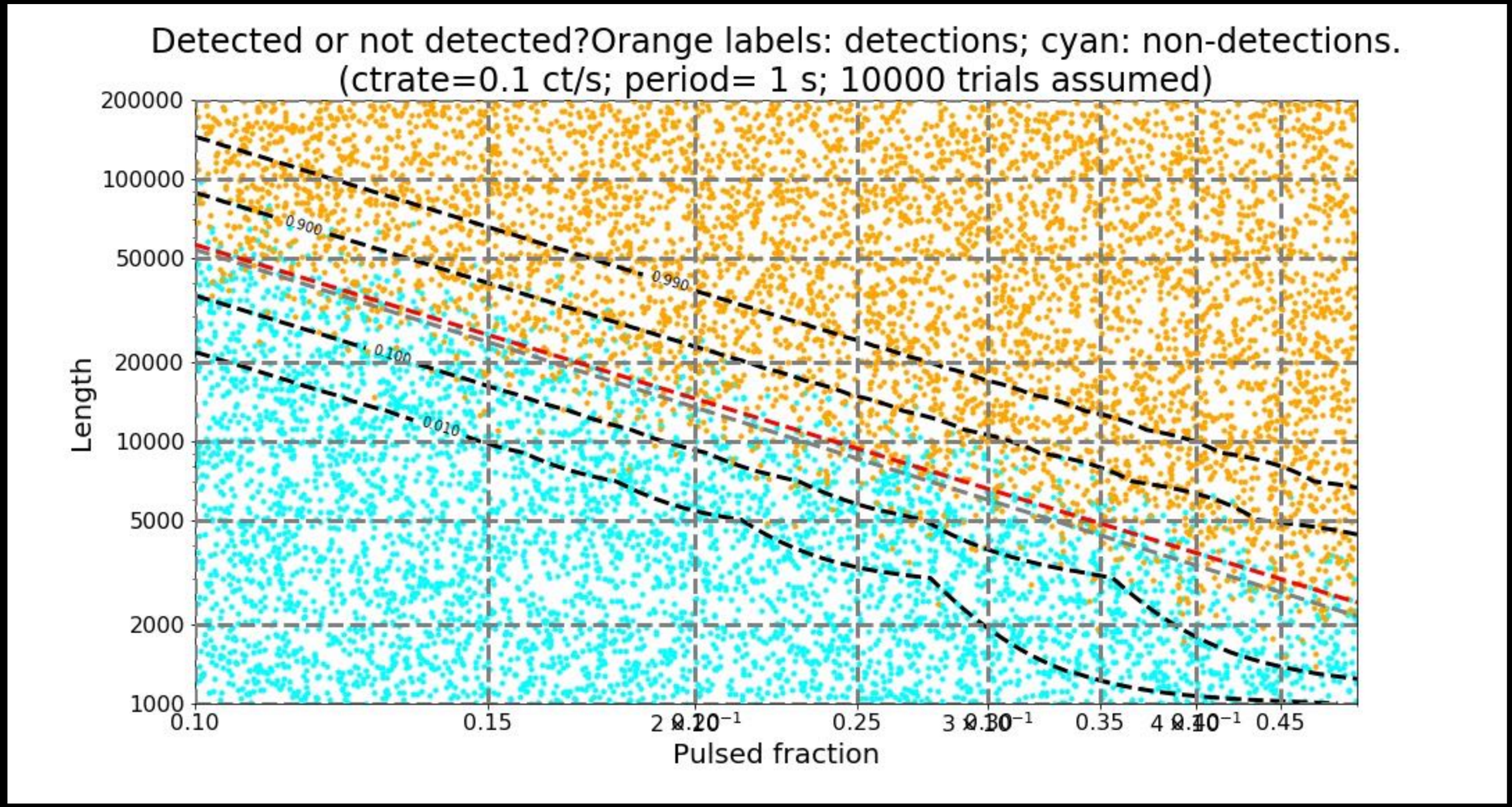
See Brumback's talk and Pike's poster!

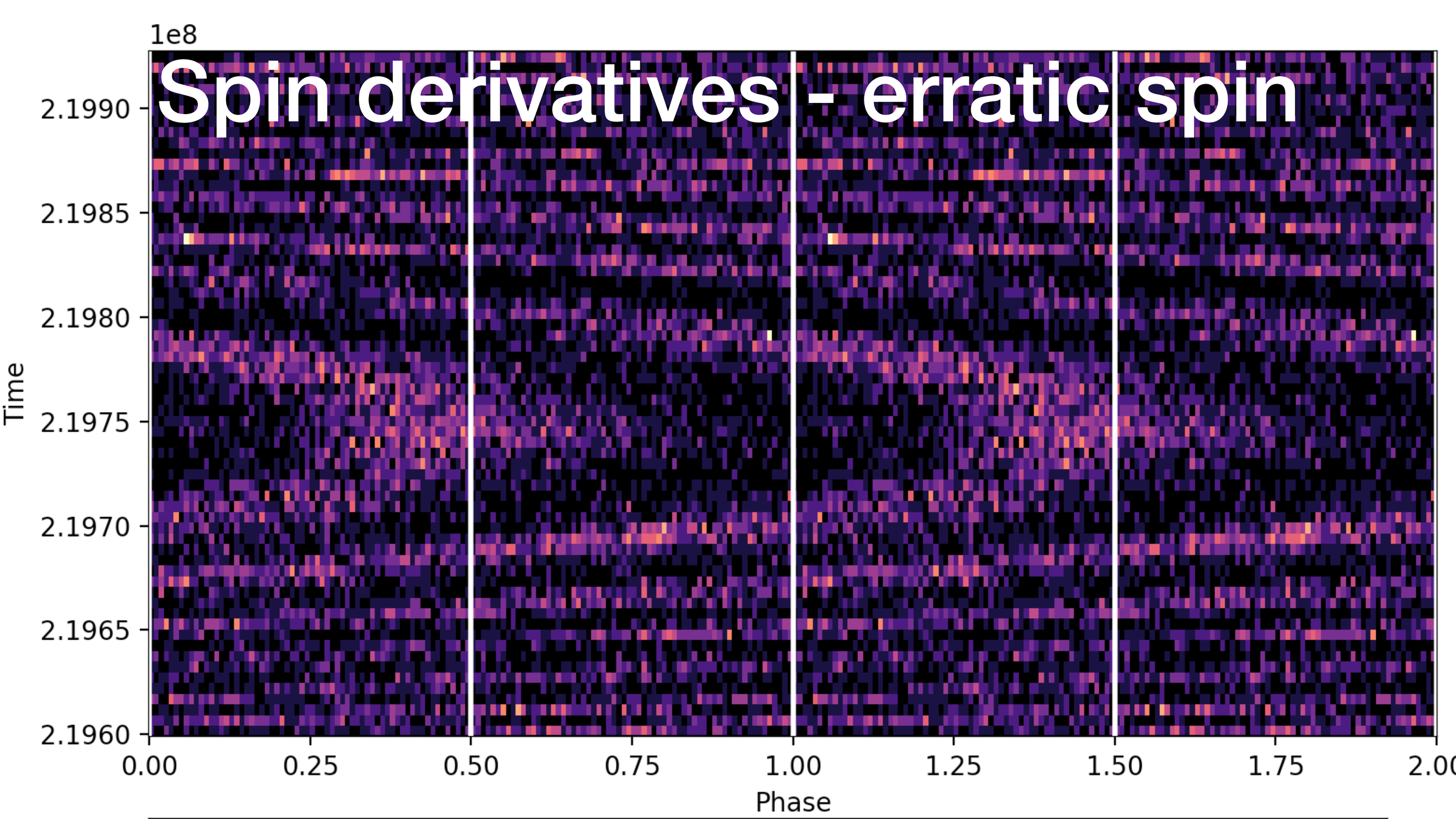
Brumback et al., submitted

Finding PULXs is complicated

Or: why haven’t we found more of these

Faint pulsations

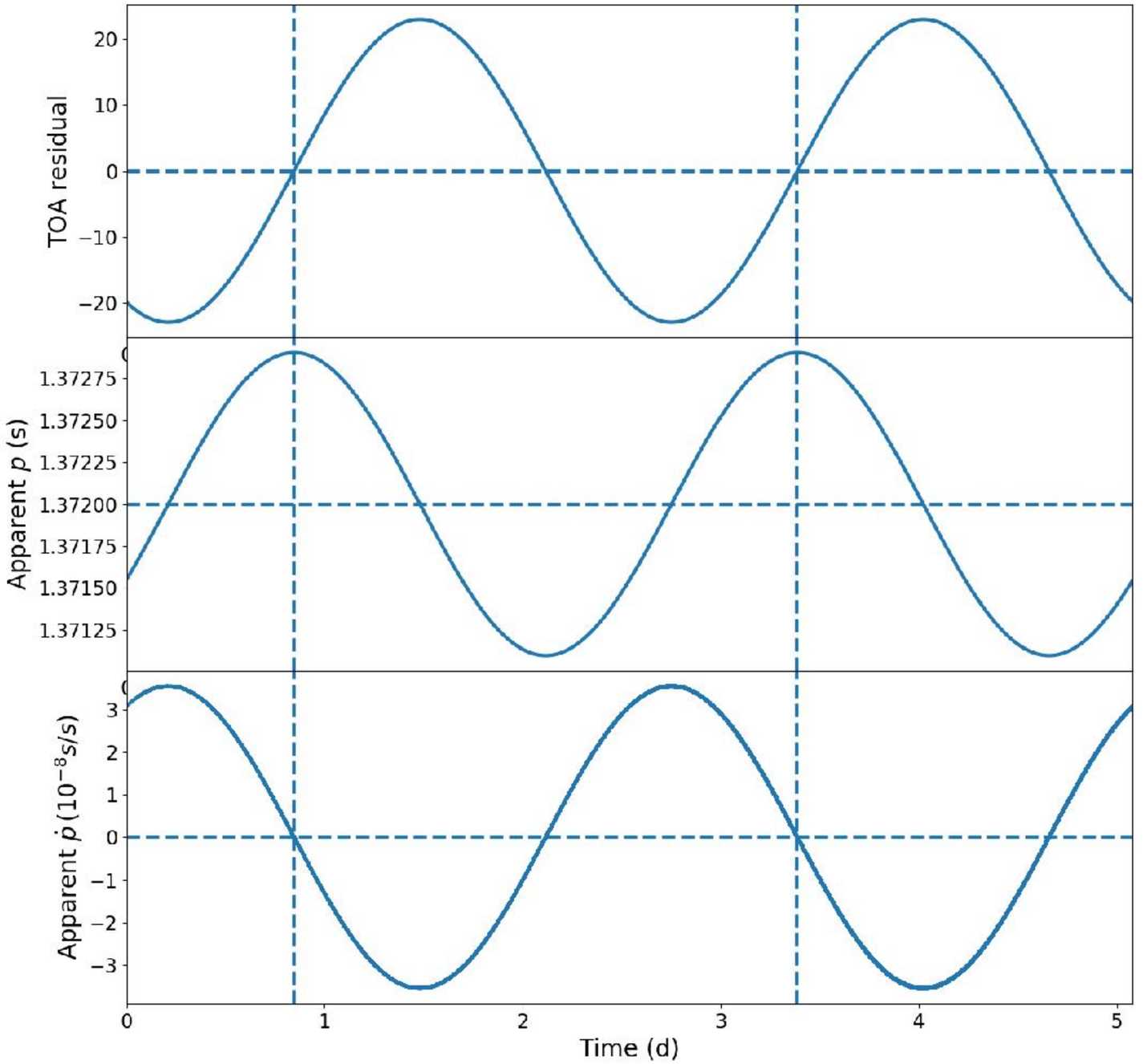



Spin derivatives - erratic spin
1e8
2.1990
2.1985
2.1980
2.1975
2.1970
2.1965
2.1960
Time
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Phase

Orbital motion

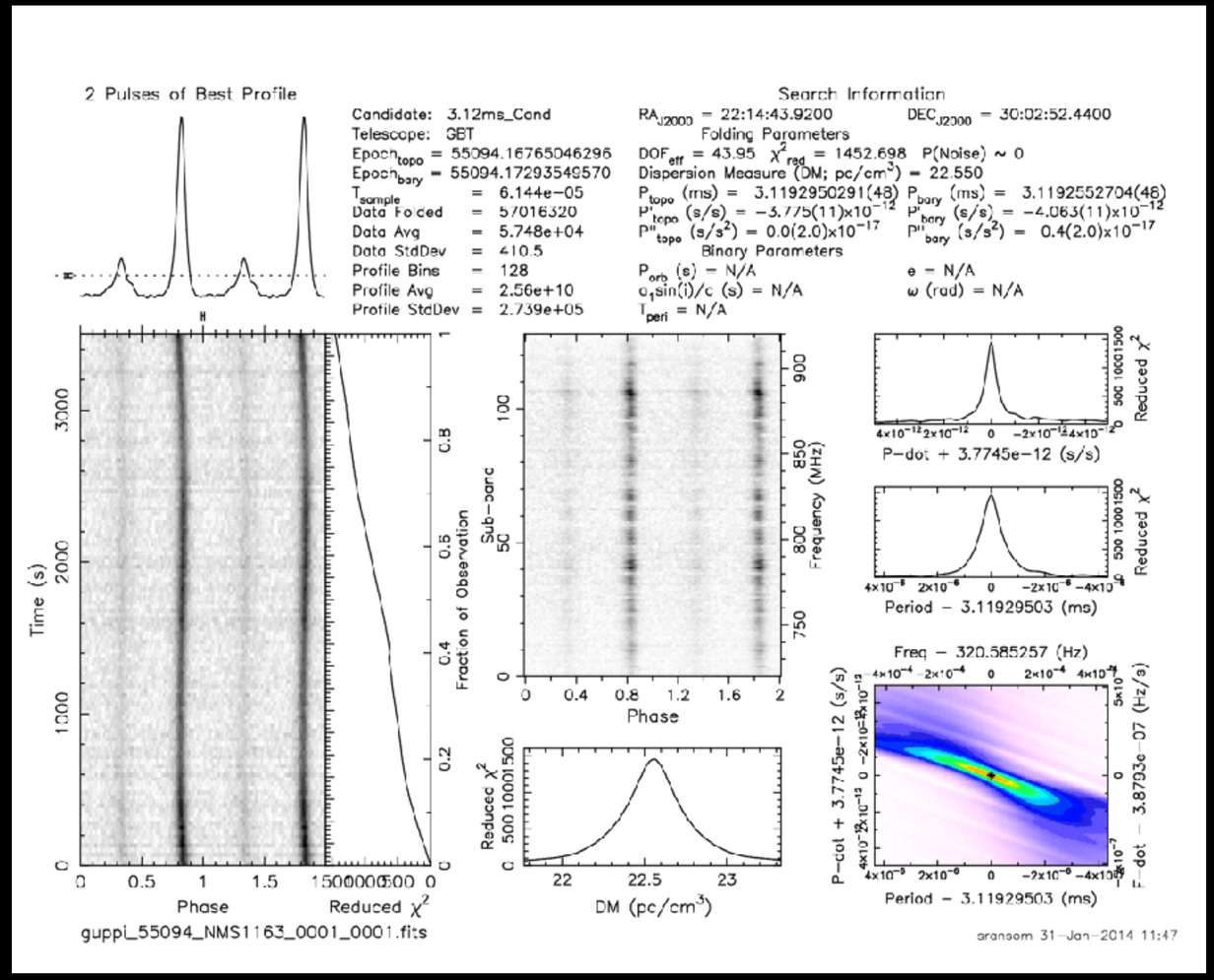
M82 X-2: Instantaneous apparent period derivative two orders of magnitude above intrinsic spin up, and changing during orbit

$$\dot{p}_{orb} \sim a \sin i \left(\frac{2\pi}{P_{orb}} \right)^2$$



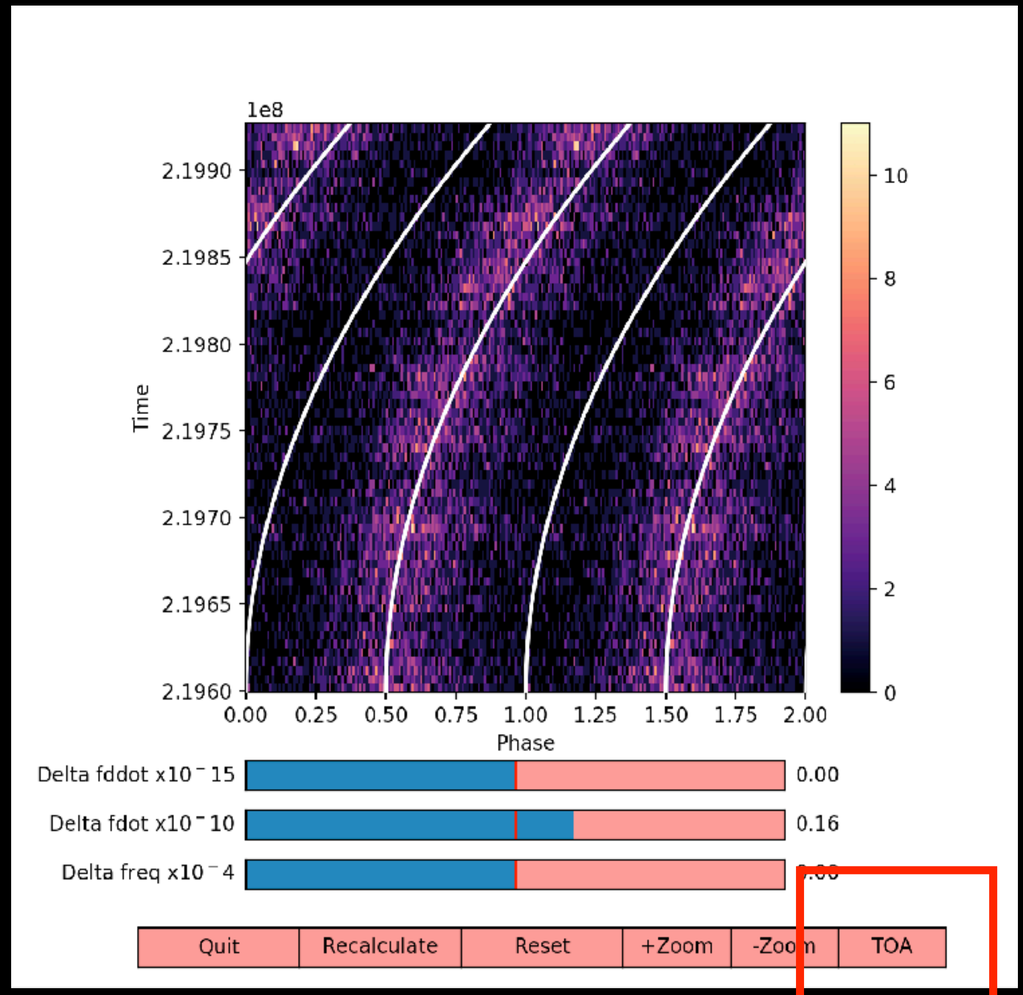
Radio pulsar software can help

- E.g.: PRESTO
- Can search for accelerated pulsars
- Highly optimized, scales to many CPUs (for GPUs too)



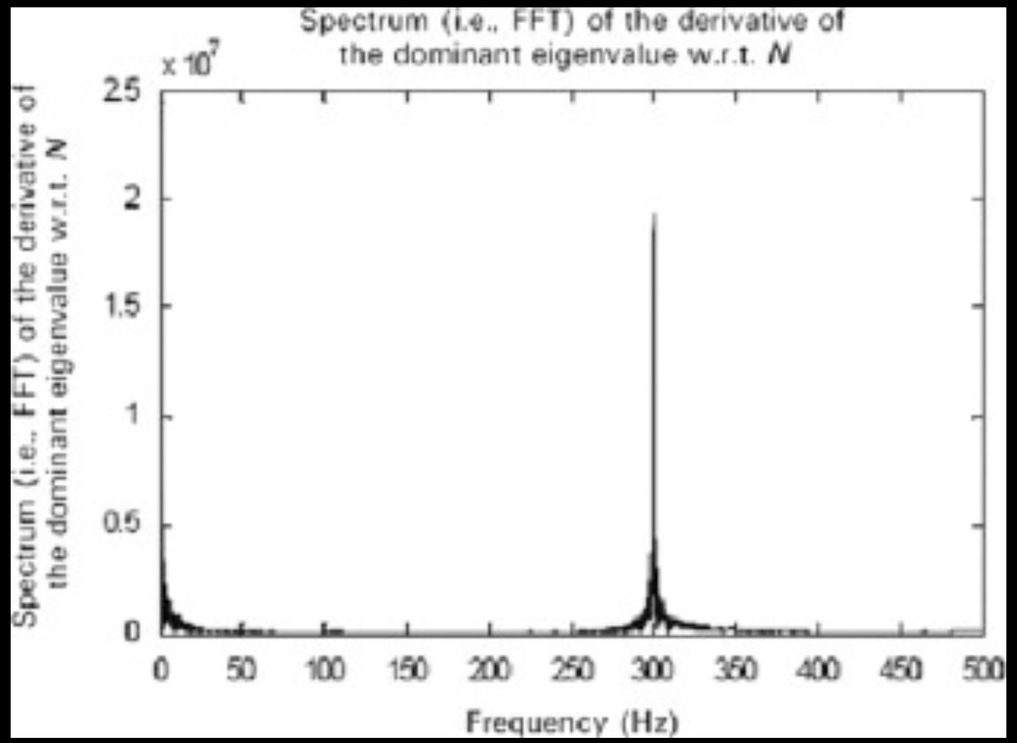
HENDRICS and DAVE

- Quick-look spectral timing tools from GUI and command line
- Lots of pulsar-related features: folding search, Z search, interactive phaseogram (picture), orbital parameter search, …
- Can produce TOAs for precise pulsar timing
- Can create binary files for PRESTO search!
- **Interested in a tutorial? Ask me or Simone Migliari**



Alternative methods

- A number of alternative methods used in SETI searches
- E.g. Karhunen-Loève Transform: solves an eigenvalue equation, decomposes signal with orthonormal, non-harmonic functions
- Scales as N^2 -> slow for long observations. Lots of work by SETI on optimization



Bottom line

- PULXs not too different from standard accreting pulsars, just more extreme.
- PULXs found thus far are *slow*: selection effect?
- Strong, erratic spin-up is common — does not correlate simply with luminosity.
- Orbital period constrained only in M82 X-2
- Possible selection effects: orbital orientation, spin properties, transient pulsations, beaming!
- -> Either we are extremely lucky, or there are many more out there.

BREAKING THE LIMITS 2018

Super-Eddington accretion onto compact objects

Castiadas (CA), Italy, October 1-5, 2018

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https://goo.gl/w97Zg6