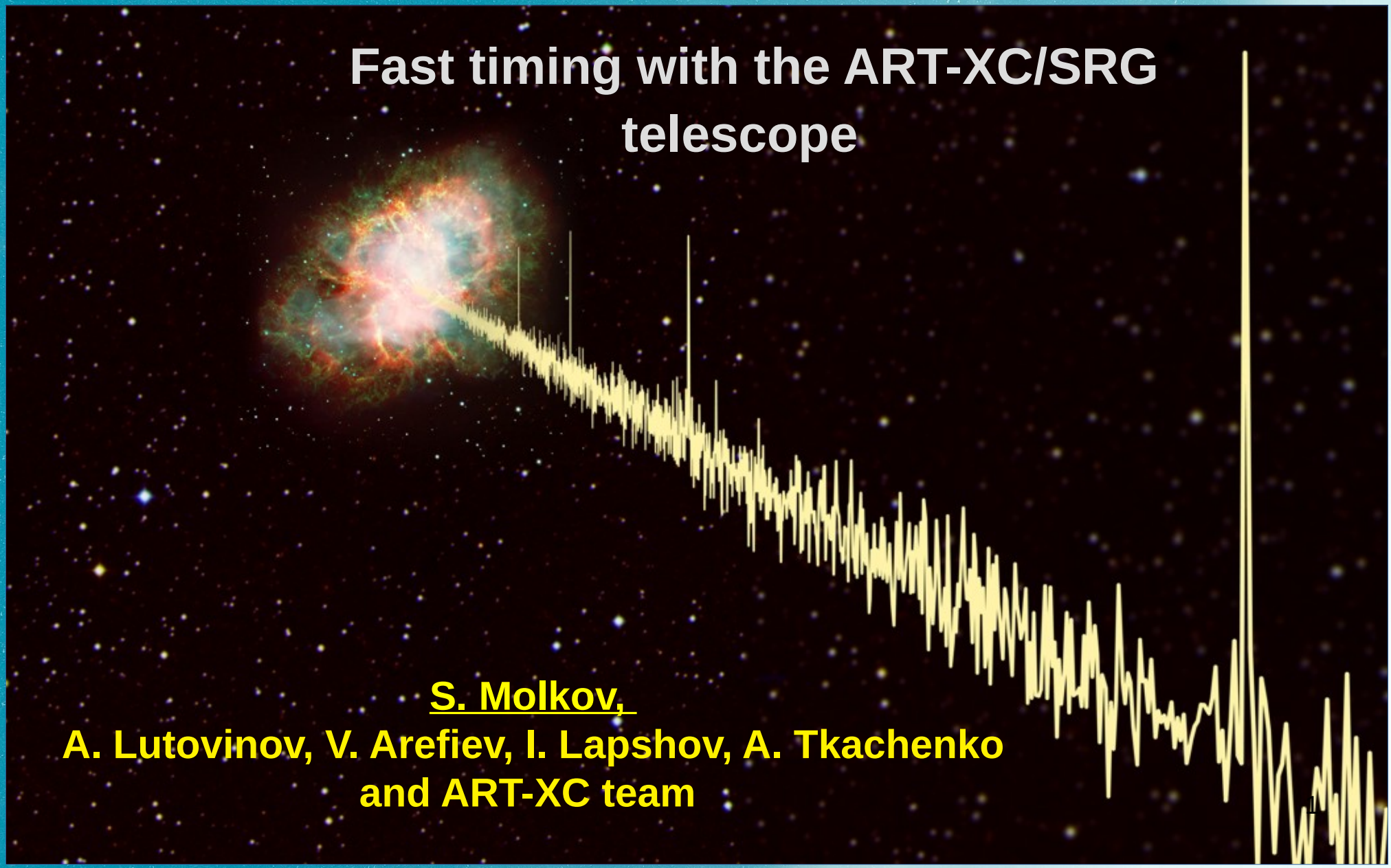
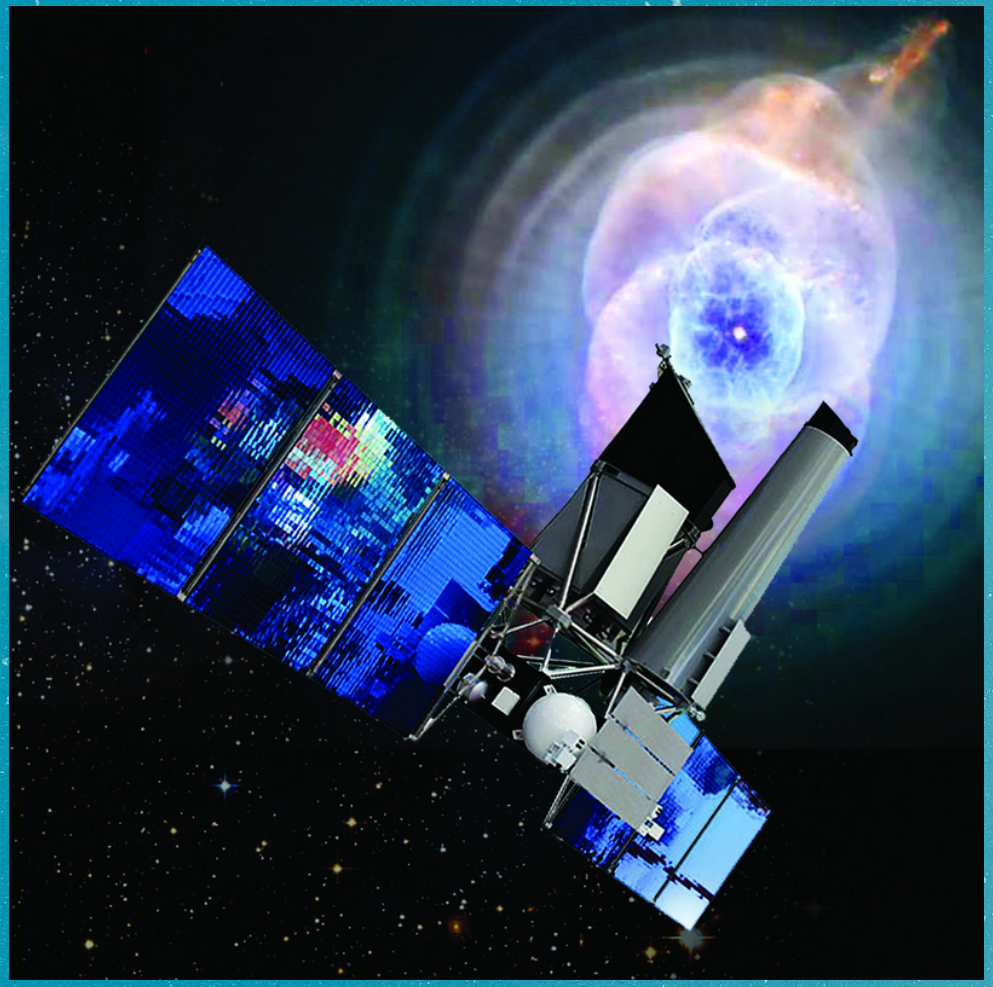
HEACOSS-2026
15-19 Jun. 2026, Erevan

Fast timing with the ART-XC/SRG telescope



S. Molkov,
A. Lutovinov, V. Arefiev, I. Lapshov, A. Tkachenko
and ART-XC team



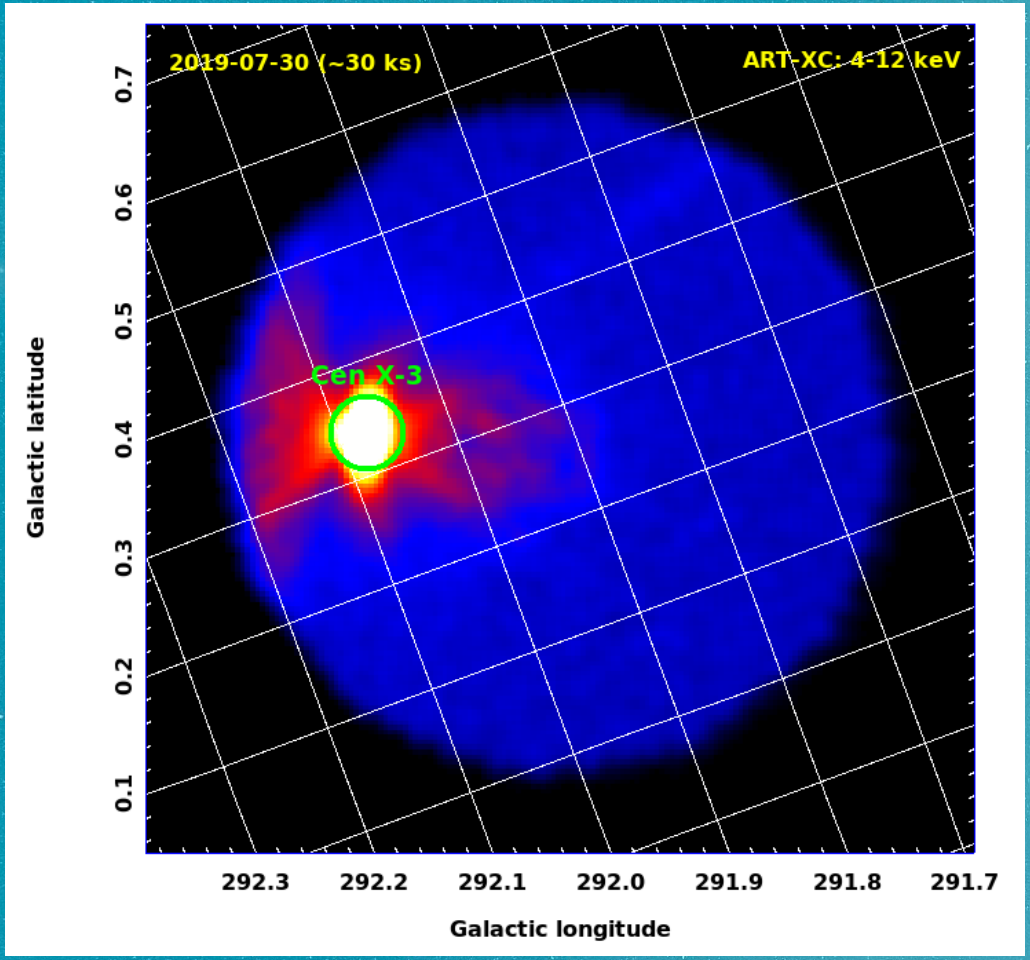
«…SRG had been designed not for timing!»
Mikhail PAVLINSKY

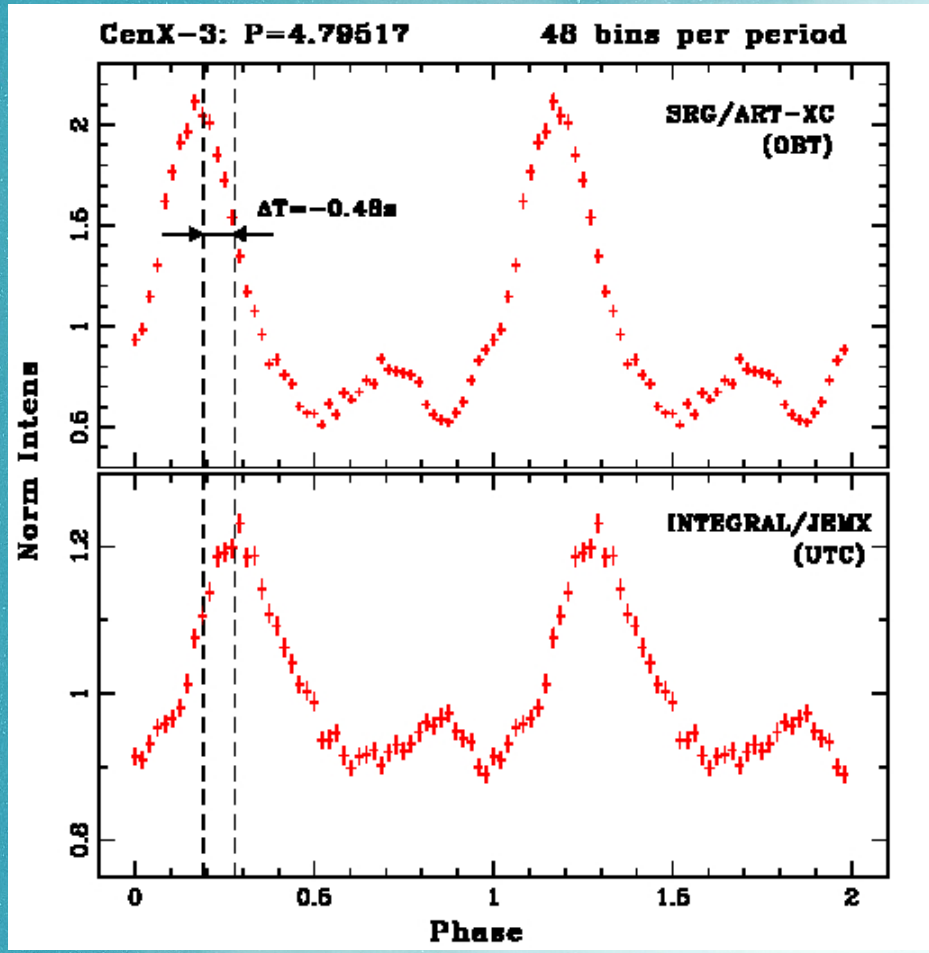
Time resolution	**23 usec**
Energy band	**4-30 keV**
Dead time	**700 usec**
Sensitivity to flux	**~1e-11 erg/s (survey mode: ~100s exp.)**
	~5e-12 erg/s (scaning mode: ~1 ks exp.)
	~5e-13 erg/s (pointing mode: ~100 ks exp.)

The main goal of the talk is to demonstrate that the ART-XC telescope, named to honor of Mikhail Pavlinsky, is great for precision timing.

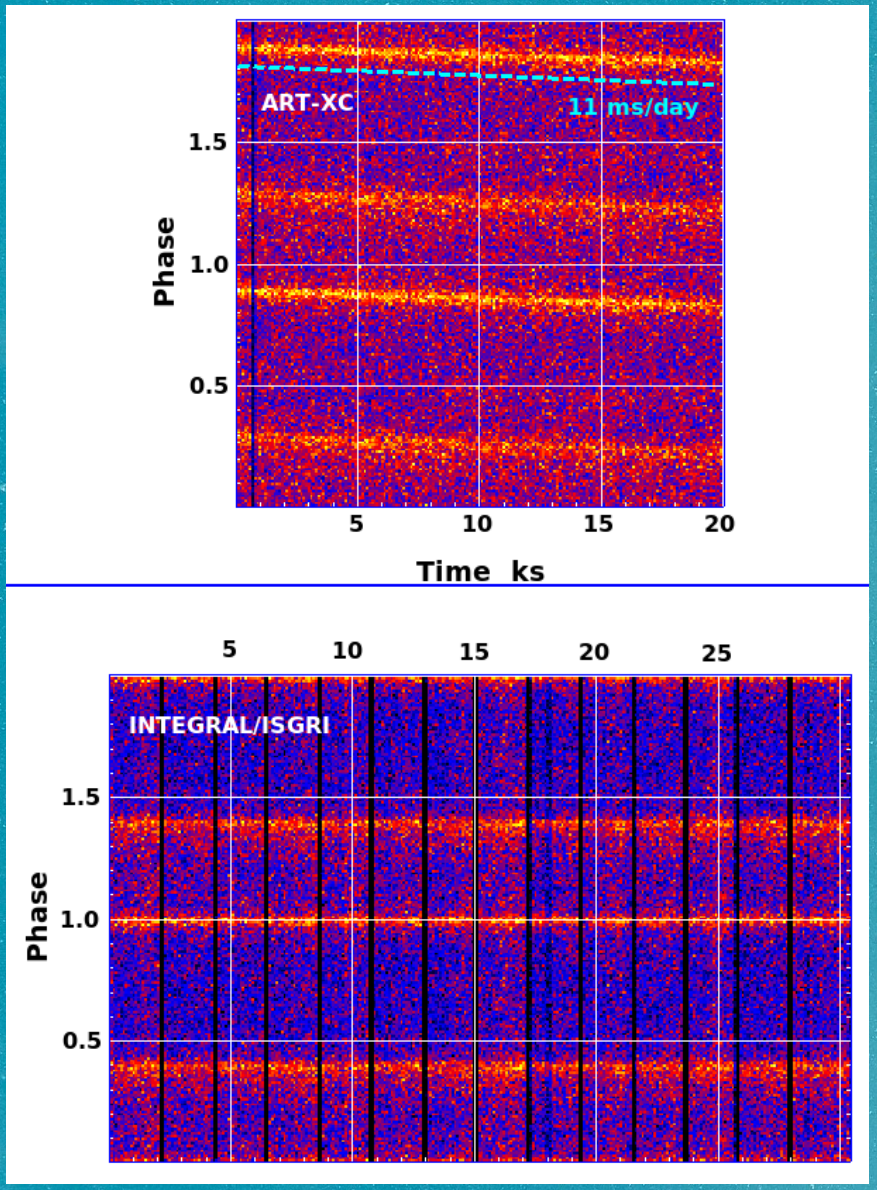
Plan of the talk:
1) calibration of on-board clock
2) detection of pulsed-emission from fast rotators
   a) rotation-powered pulsars
   b) accreation powered millisecond pulsars

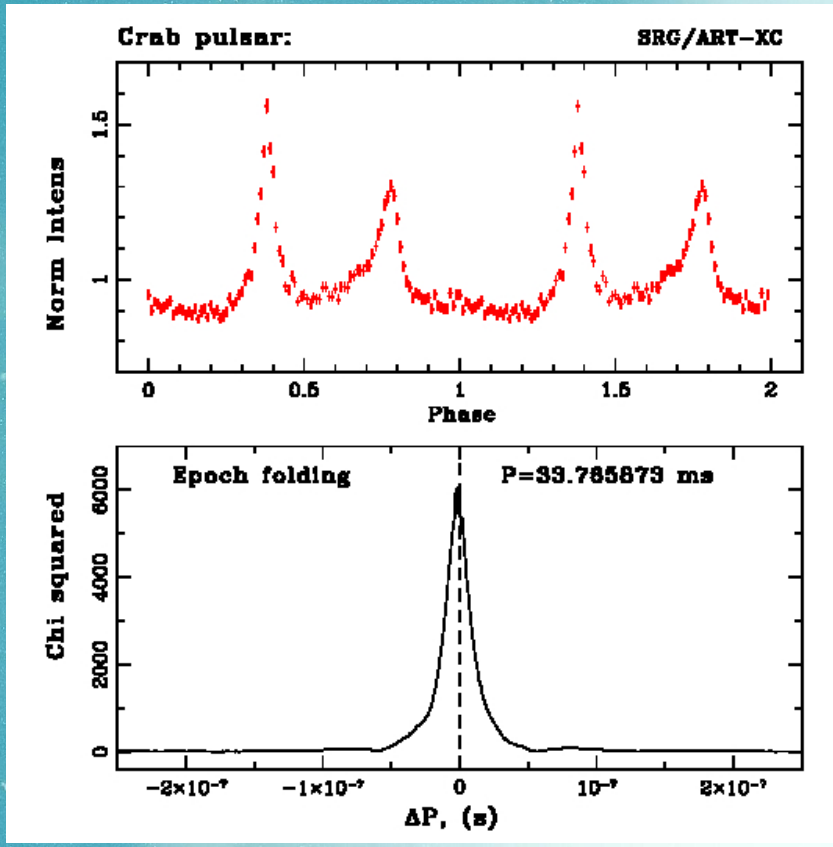
First light — CenX-3





INTEGRAL and ART-XC simultaneous Crab pulsar observation



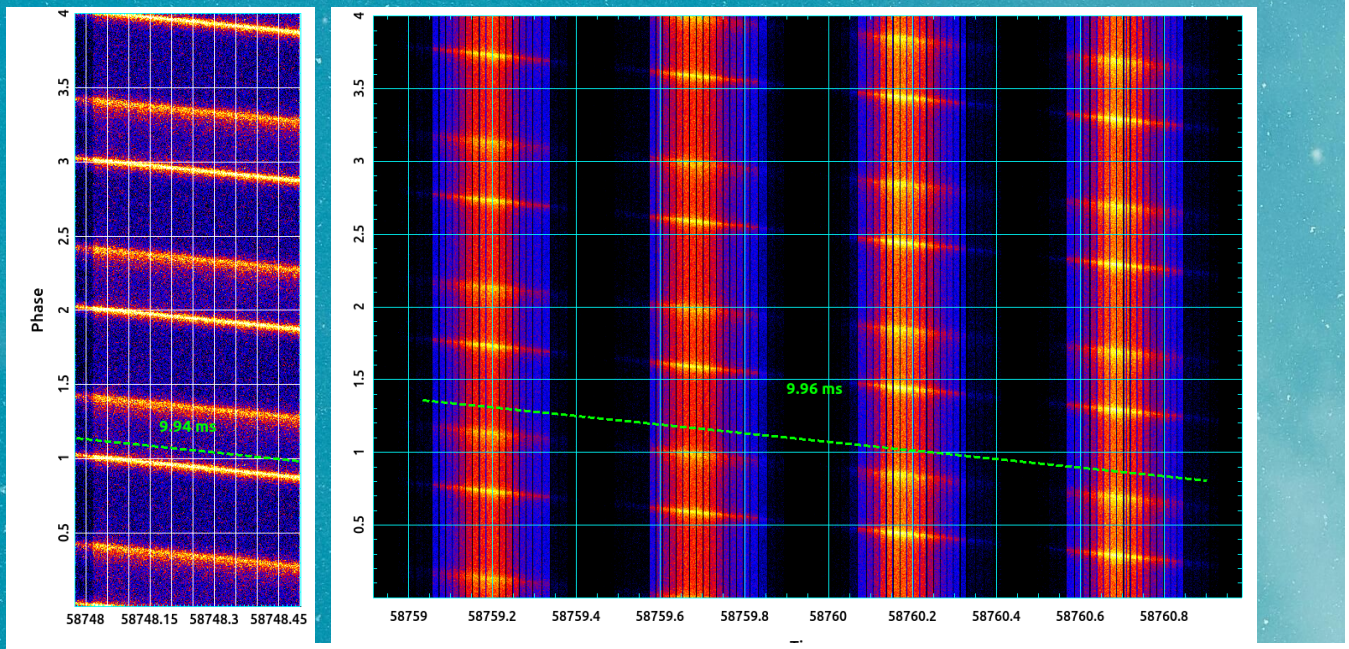


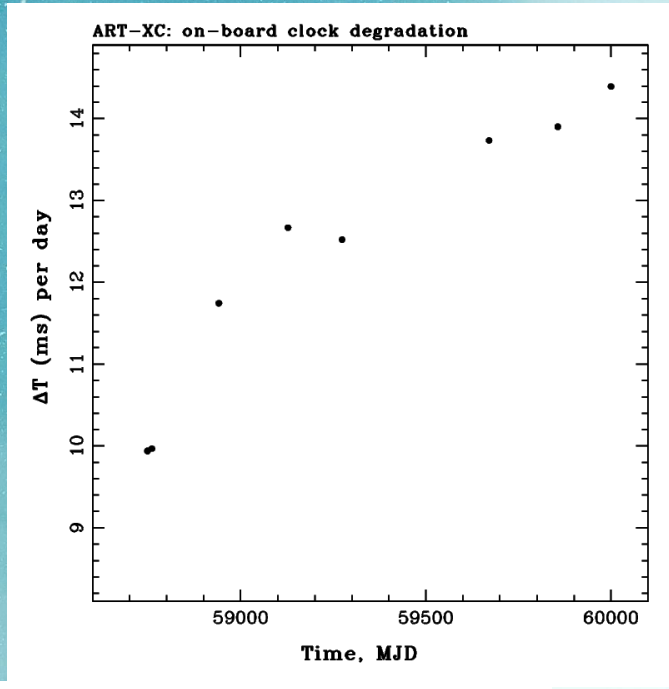
ephemeris:

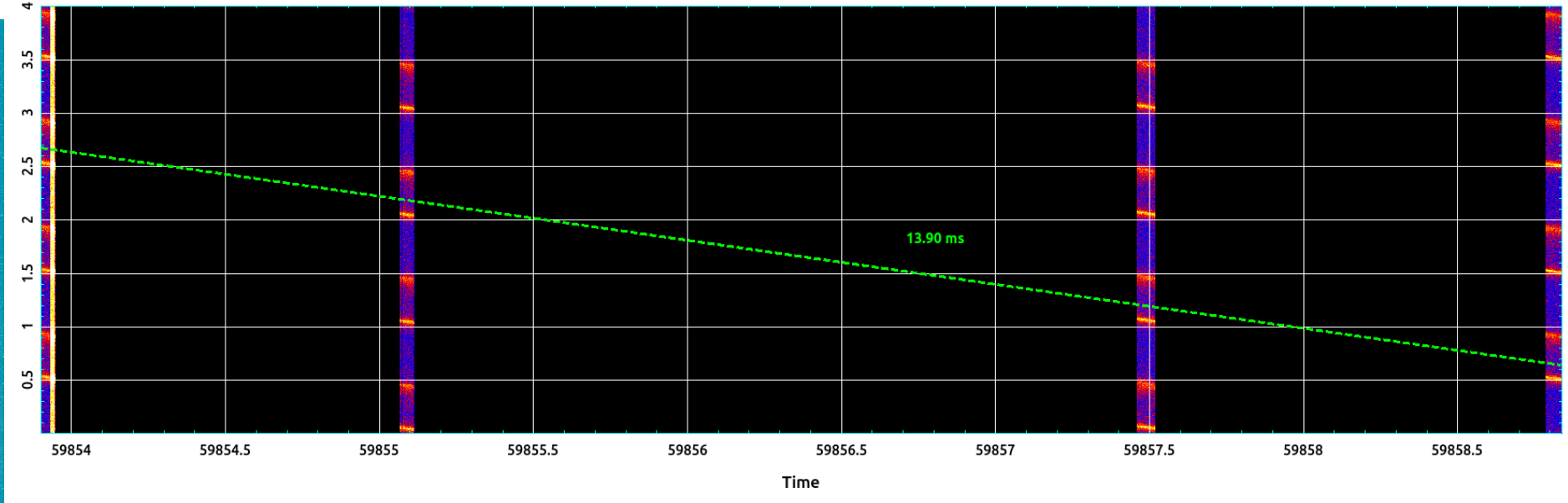
	T0 (day)	Freq Hz	dF x 10^{-15} Hz^{-2}
58697-58711	58703.01612500	29.616384501600	-368553.110
58711-58727	**58719.02177700**	**29.615875133900**	**-368416.810**
58727-58756	58741.02436300	29.615174893500	-368362.250

JODRELL BANK CRAB PULSAR MONTHLY EPHEMERIS
http://www.jb.man.ac.uk/pulsar/crab.html

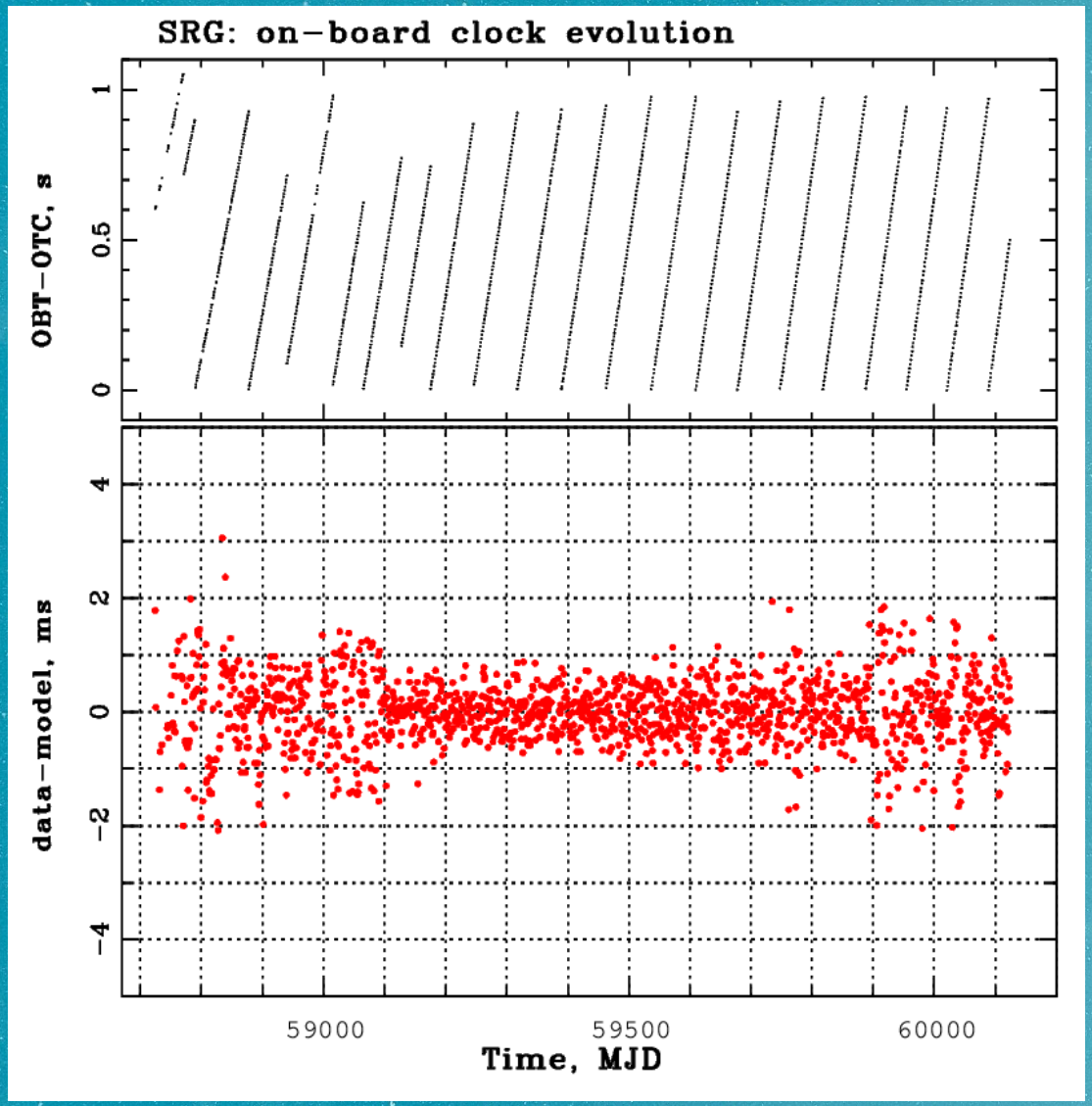
ART-XC: timing of Crab pulsar



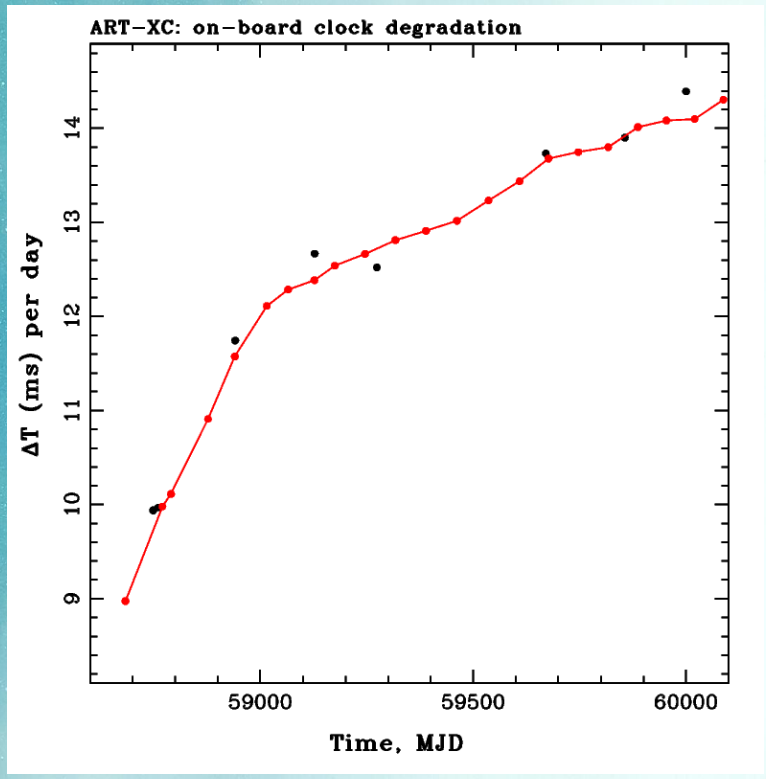




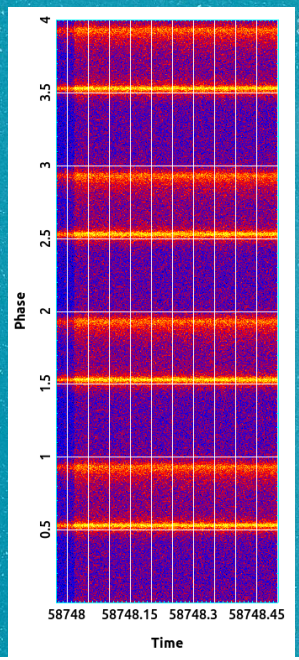
On-board clock model

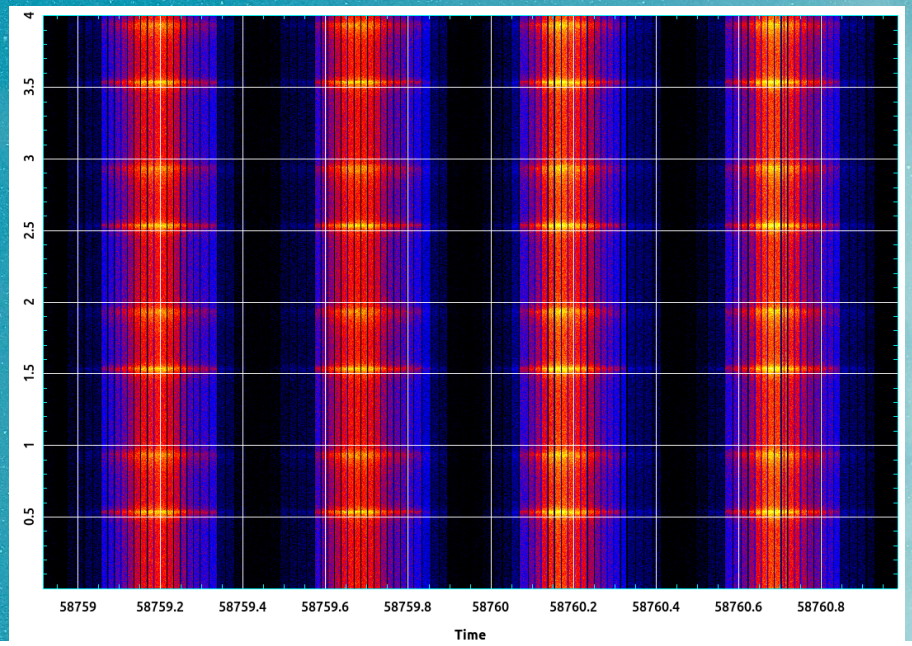


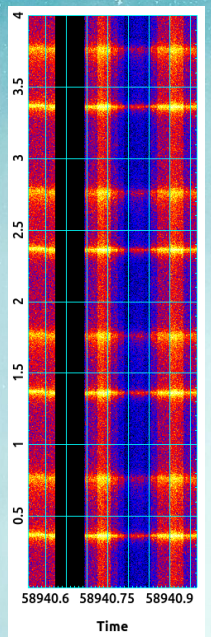
##		T0	ph0 (s)	p0 (s/day)	pdot0 (s/day/day)
0	58683.70665278 58770.95885017	58683.0	0.214759	8.97557E-03	6.6861E-06
1	58770.95885017 58790.20487847	58770.0	0.700390	9.97938E-03	6.0950E-06
2	58790.20487847 58877.61070023	58790.0	0.002211	10.11288E-03	5.1713E-06
3	58877.61070023 58940.72223958	58877.0	-0.004863	10.91159E-03	5.8454E-06
4	58940.72223958 59015.95302662	58940.0	0.080575	11.57353E-03	3.4183E-06
5	59015.95302662 59065.70999421	59015.0	0.006955	12.11227E-03	1.1520E-06
6	59065.70999421 59127.88196181	59065.0	-0.004688	12.28647E-03	1.0638E-06
7	59127.88196181 59175.78027199	59127.0	0.136411	12.38556E-03	1.7274E-06
8	59175.78027199 59246.37501736	59175.0	-0.005073	12.54002E-03	0.9122E-06
9	59246.37501736 59317.63873264	59246.0	0.010070	12.66504E-03	1.1022E-06
10	59317.63873264 59389.92222801	59317.0	-0.005446	12.81152E-03	0.7567E-06
11	59389.92222801 59462.68764468	59389.0	-0.008878	12.91106E-03	0.8534E-06
12	59462.68764468 59536.62046875	59462.0	-0.002079	13.01796E-03	1.3406E-06
13	59536.62046875 59609.66362847	59536.0	-0.006478	13.23461E-03	1.4854E-06
14	59609.66362847 59677.90671875	59609.0	-0.007339	13.43975E-03	1.5431E-06
15	59677.90671875 59747.81067708	59677.0	-0.011640	13.68049E-03	0.8297E-06
16	59747.81067708 59817.79226273	59747.0	-0.005070	13.74837E-03	0.8350E-06
17	59817.79226273 59887.90201968	59817.0	-0.008319	13.79985E-03	1.2005E-06
18	59887.90201968 59954.63901042	59887.0	-0.007027	14.01389E-03	0.1625E-06
19	59954.63901042 60020.76416088	59954.0	-0.007419	14.08346E-03	1.2479E-06
20	60020.76416088 60088.94051505	60020.0	-0.011824	14.10003E-03	1.9958E-06
21	60088.94051505 62000.00000000	60088.0	-0.013303	14.30584E-03	0.9038E-06

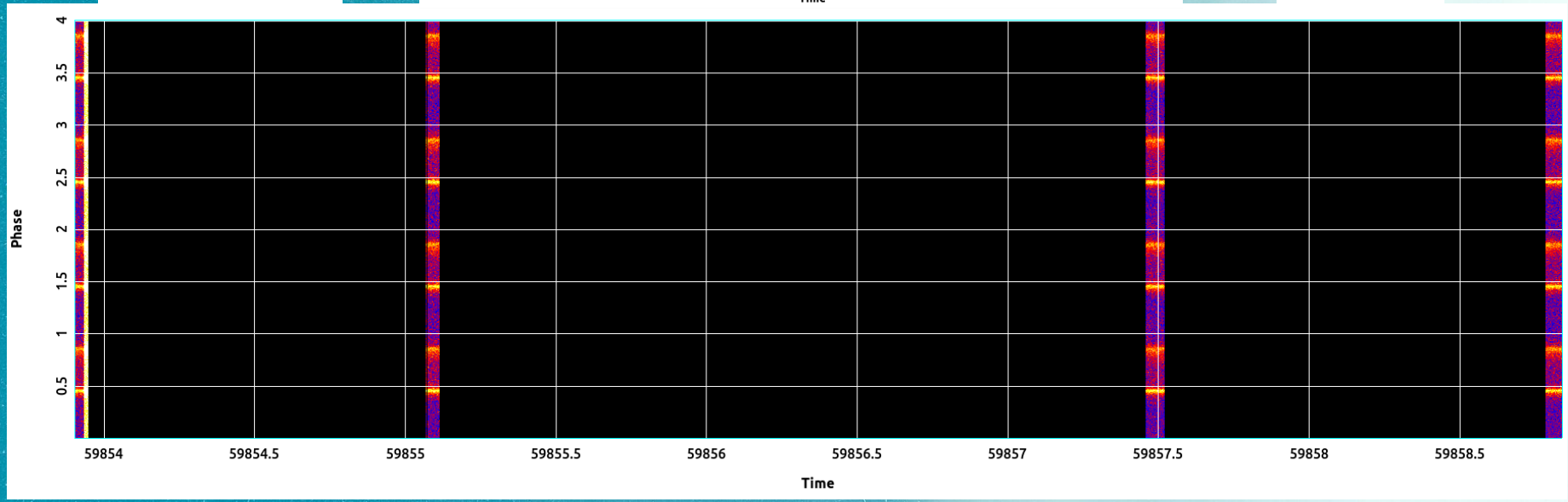


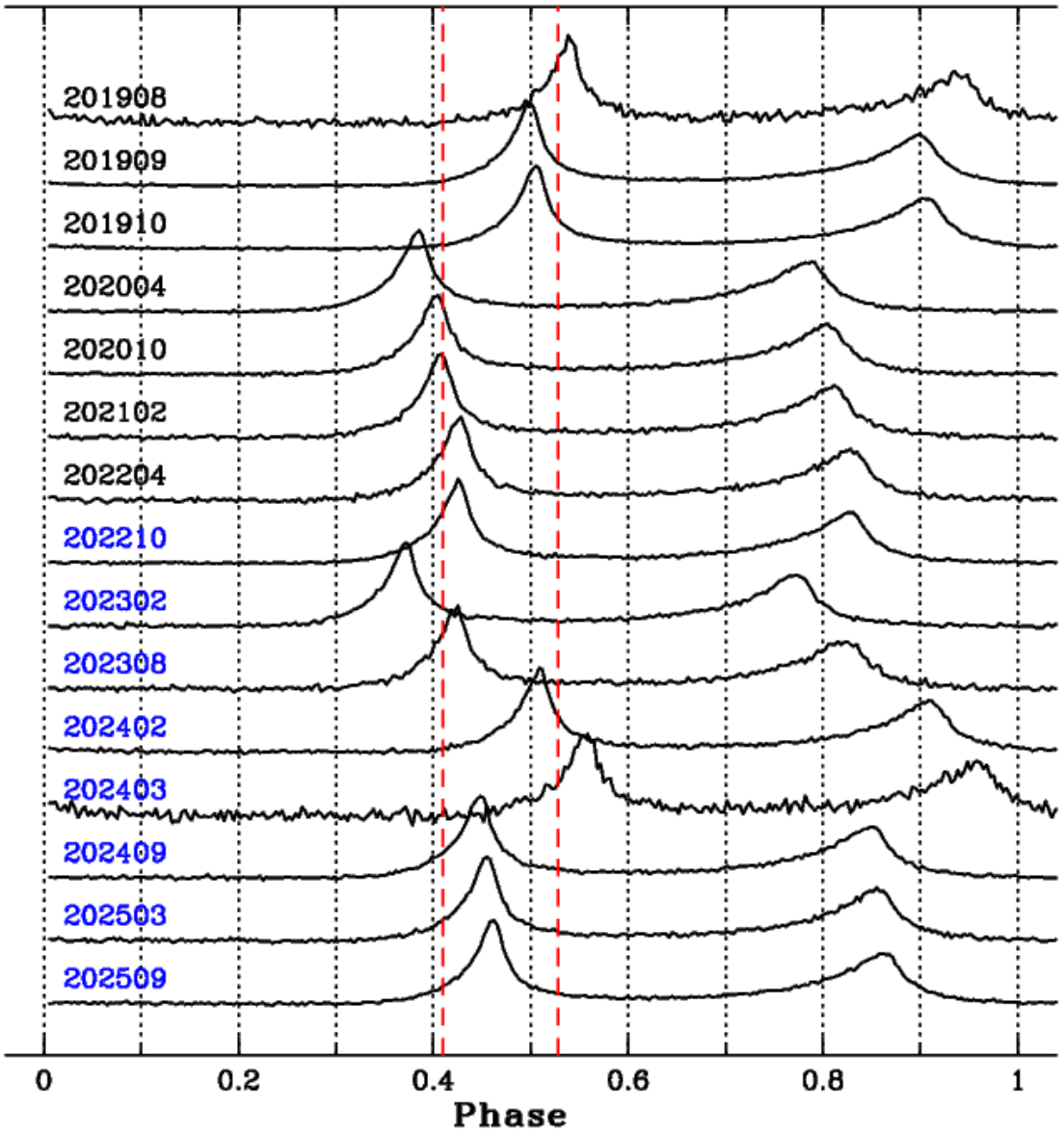
On-board clock model

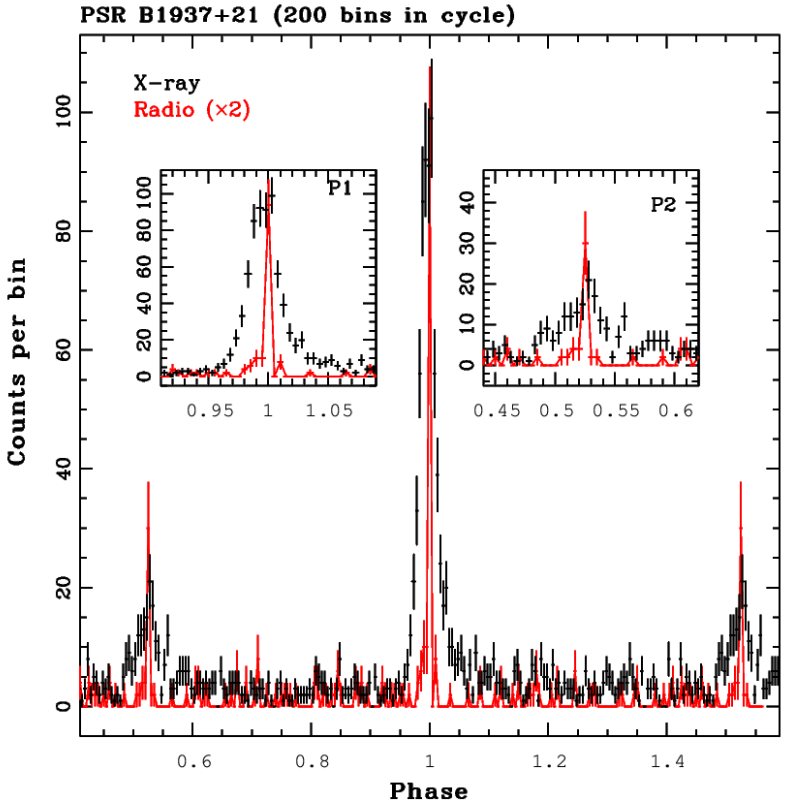








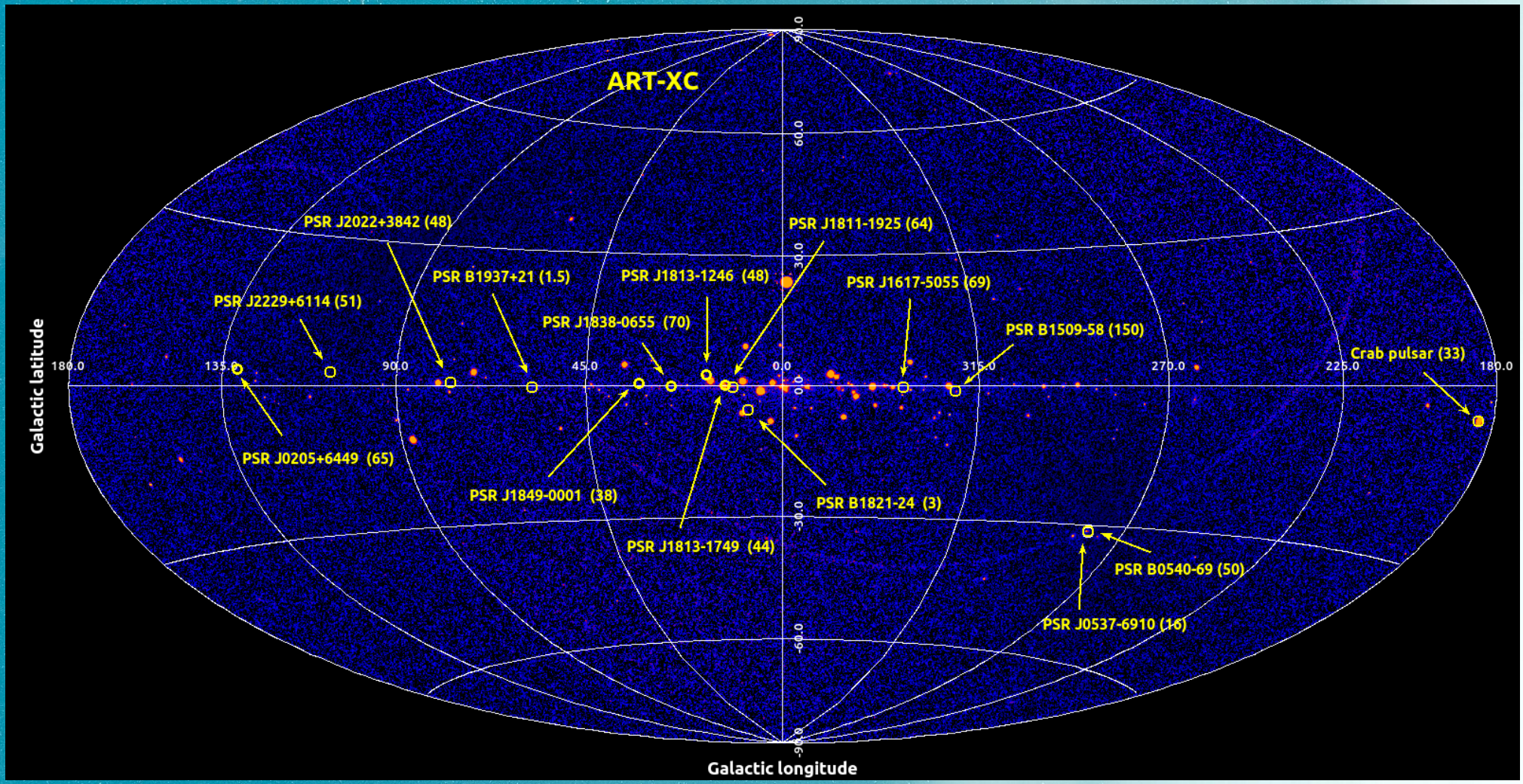


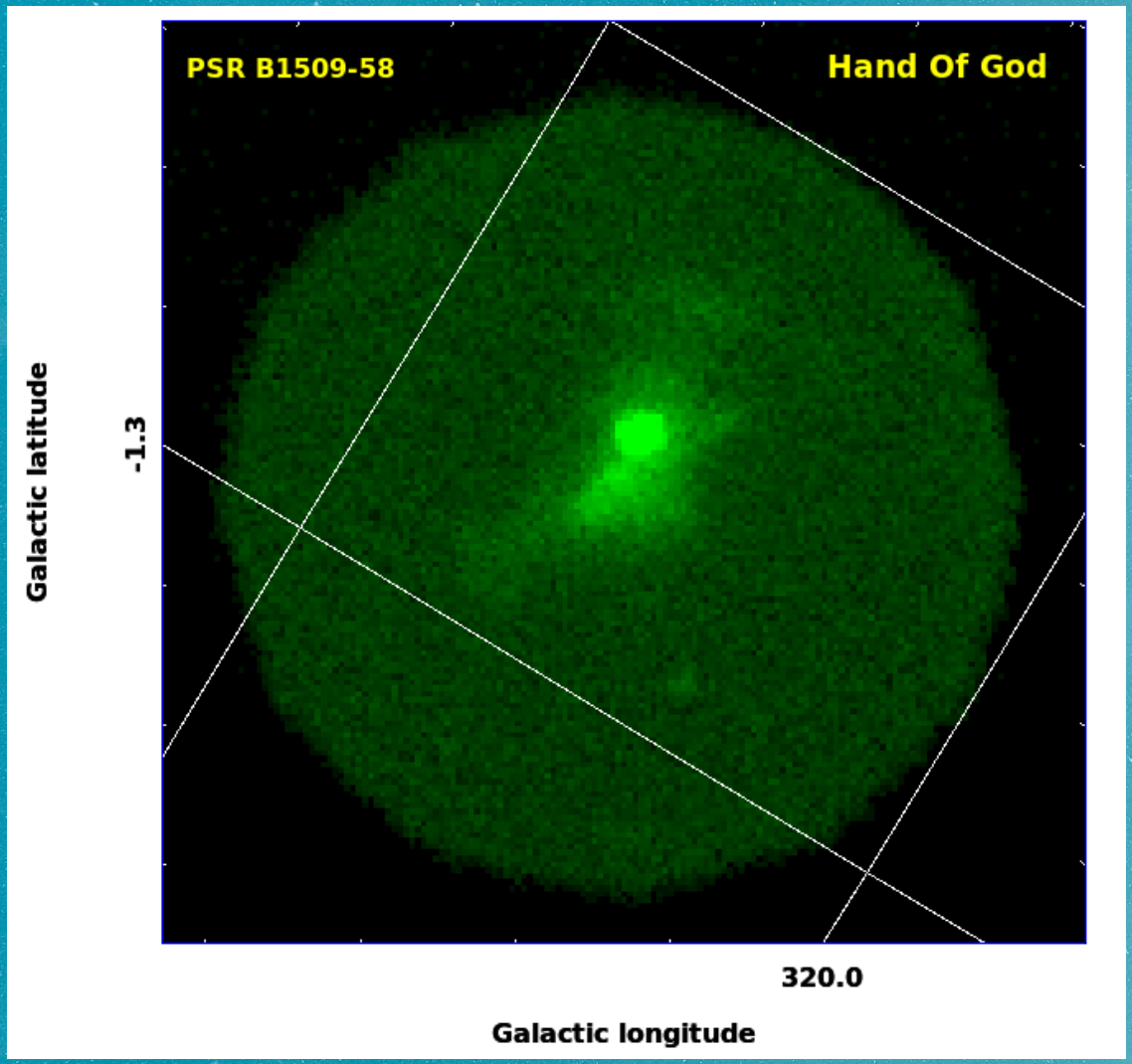


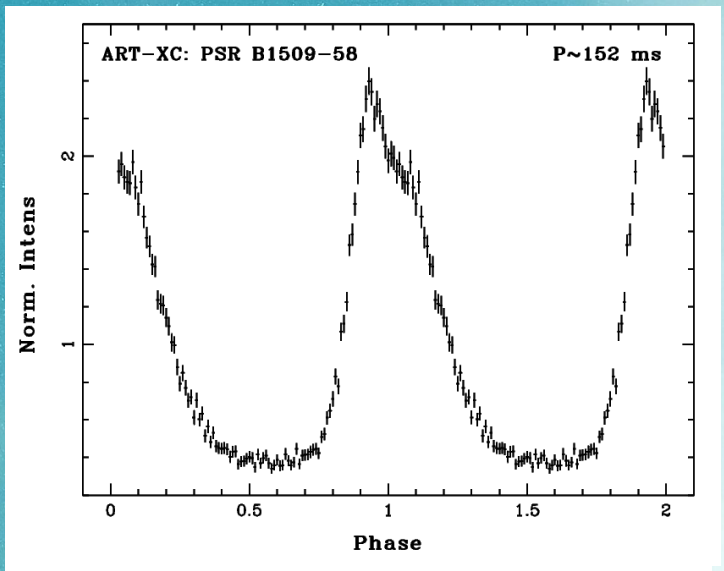
a) relative timing accuracy – systematic frequency uncertainty <1e-9 Hz

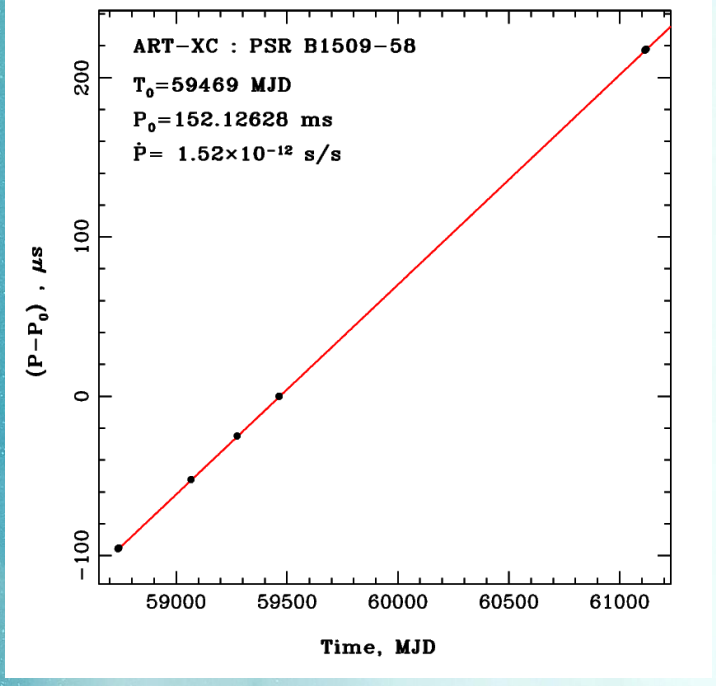
b) absolute timing accuracy – few tens of milliseconds

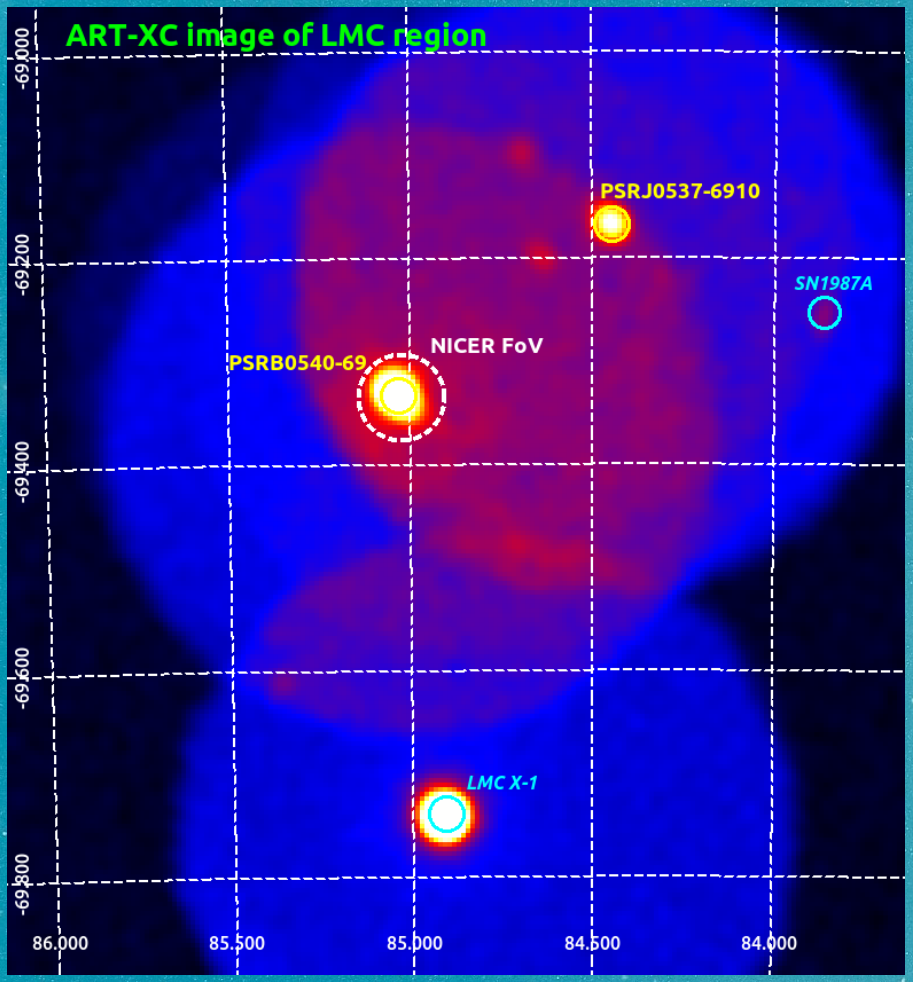
Rotation-Powered Pulsars

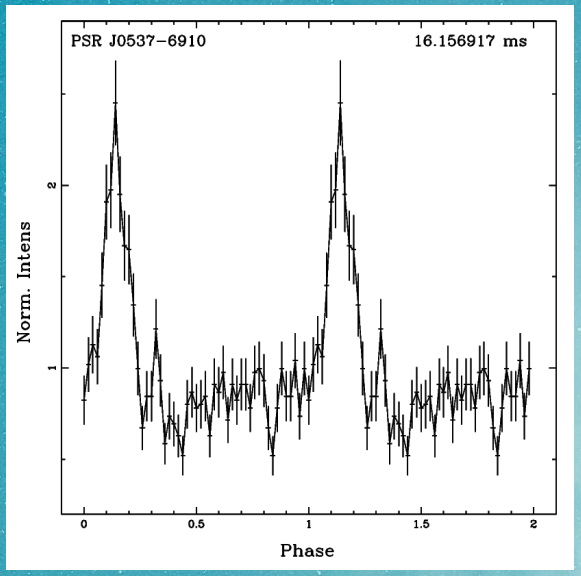


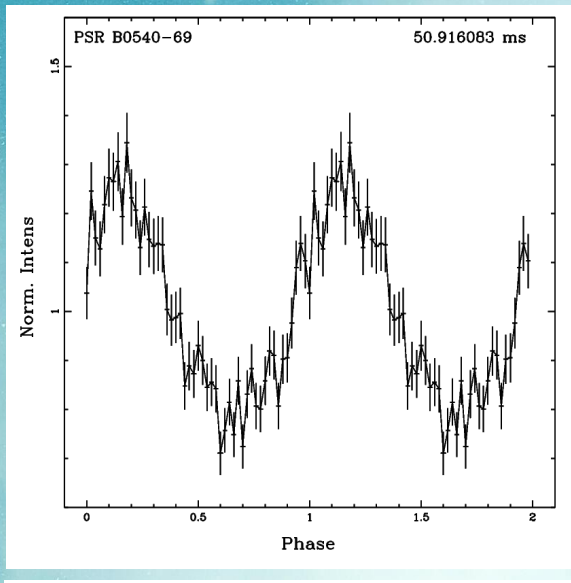

PSR B1509-58
Hand Of God
Galactic latitude
-1.3
320.0
Galactic longitude

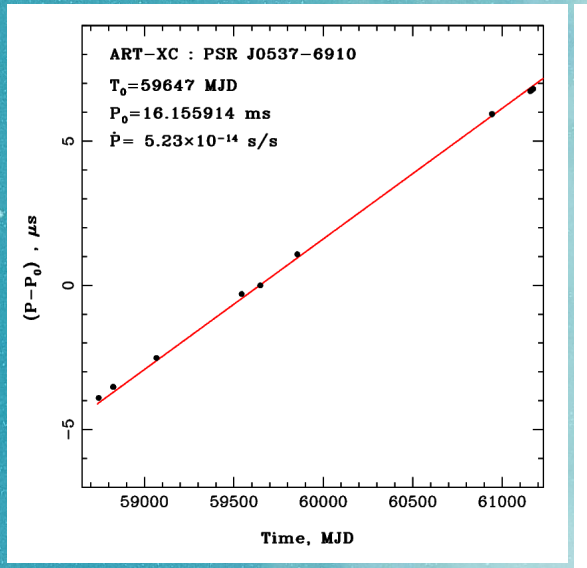

ART-XC: PSR B1509-58
P~152 ms
Norm. Intens
1
2
0
0.5
1
1.5
2
Phase

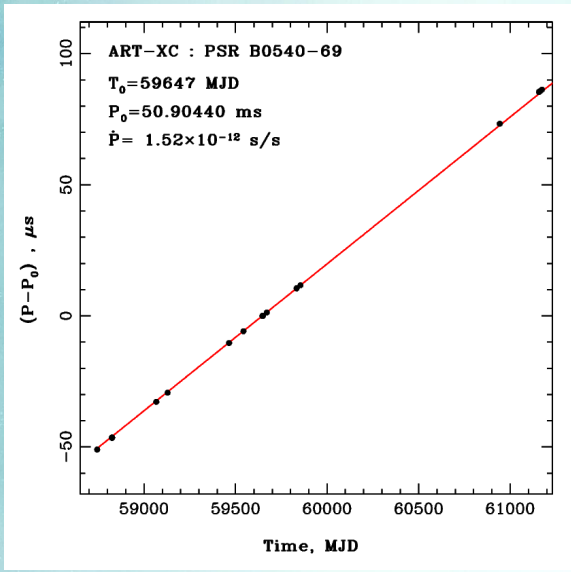

ART-XC : PSR B1509-58
T0=59469 MJD
P0=152.12628 ms
Ṗ= 1.52×10⁻¹² s/s
(P−P0) , μs
200
100
0
−100
59000
59500
60000
60500
61000
Time, MJD


ART-XC image of LMC region
PSRJ0537-6910
SN1987A
NICER FoV
PSRB0540-69
LMC X-1
-69.000
-69.200
-69.400
-69.600
-69.800
86.000
85.500
85.000
84.500
84.000

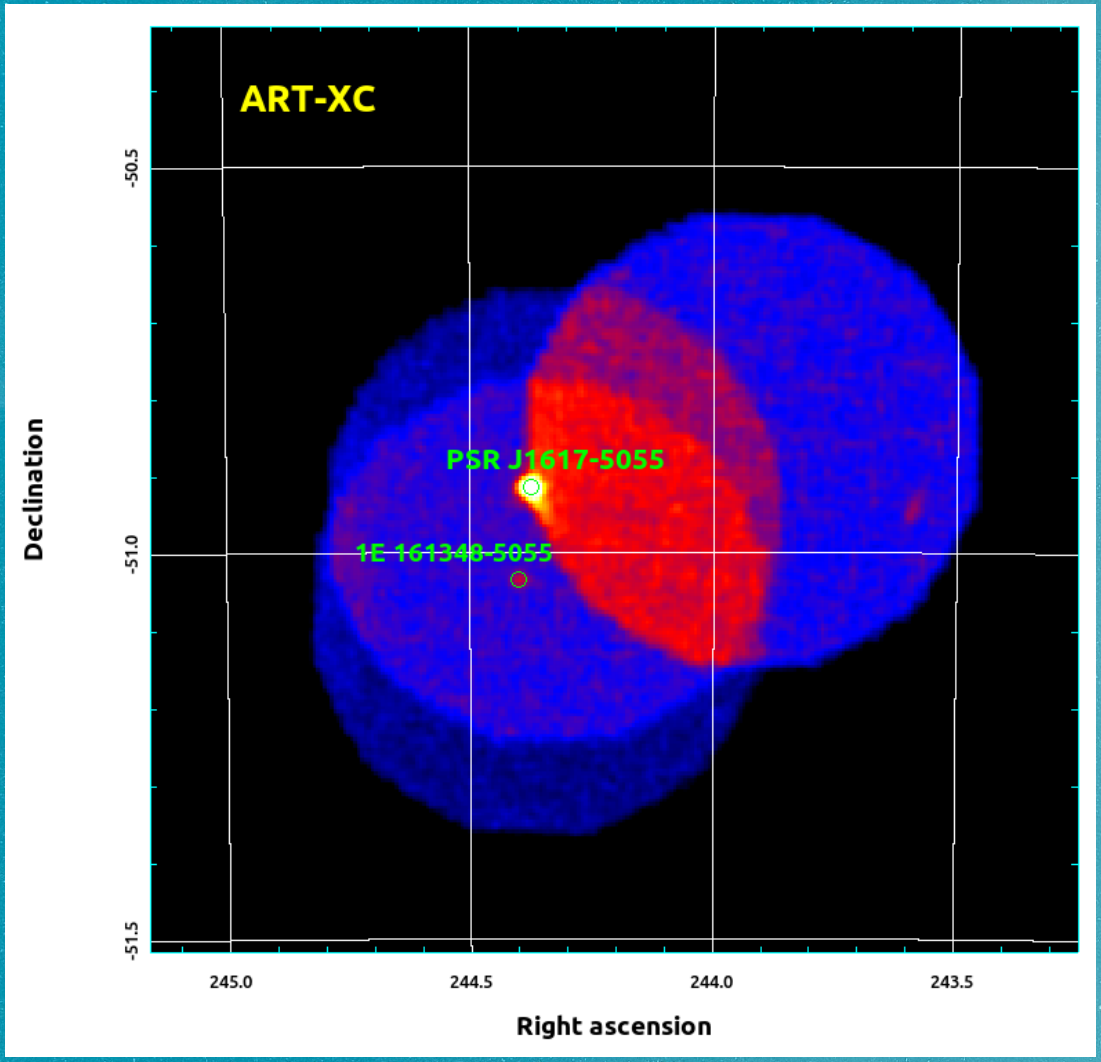

PSR J0537−6910
16.156917 ms
Norm. Intens
Phase

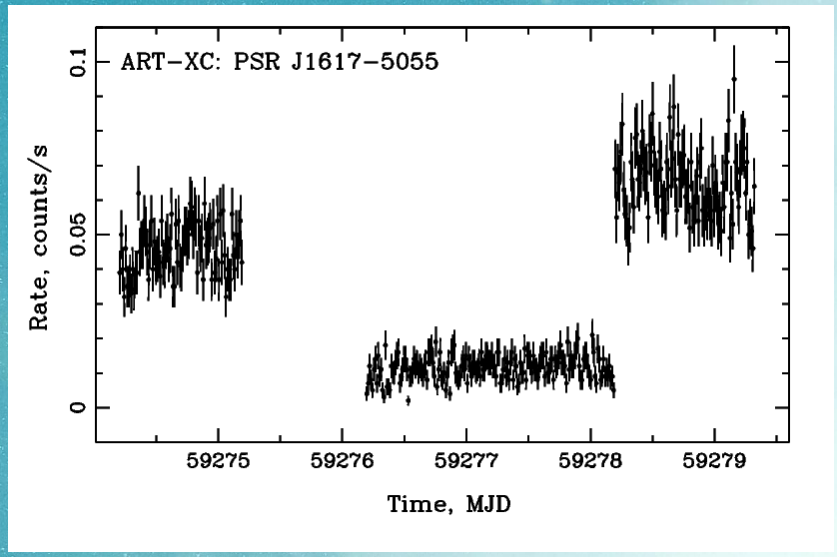

PSR B0540−69
50.916083 ms
Norm. Intens
Phase

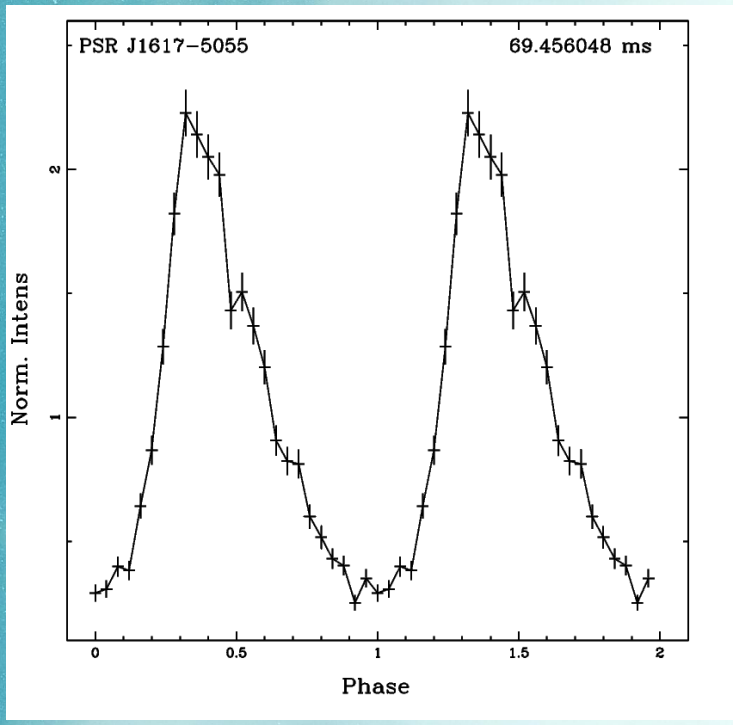

ART−XC : PSR J0537−6910
T0=59647 MJD
P0=16.155914 ms
Ṗ= 5.23×10⁻¹⁴ s/s
(P−P0) , μs
Time, MJD


ART−XC : PSR B0540−69
T0=59647 MJD
P0=50.90440 ms
Ṗ= 1.52×10⁻¹² s/s
(P−P0) , μs
Time, MJD

1-6 Mar. 2021 (eROSITA thermal tests)

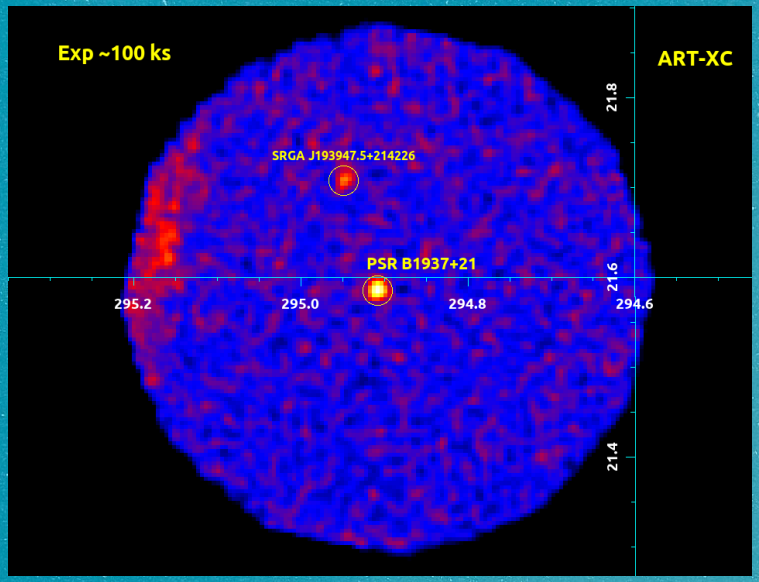


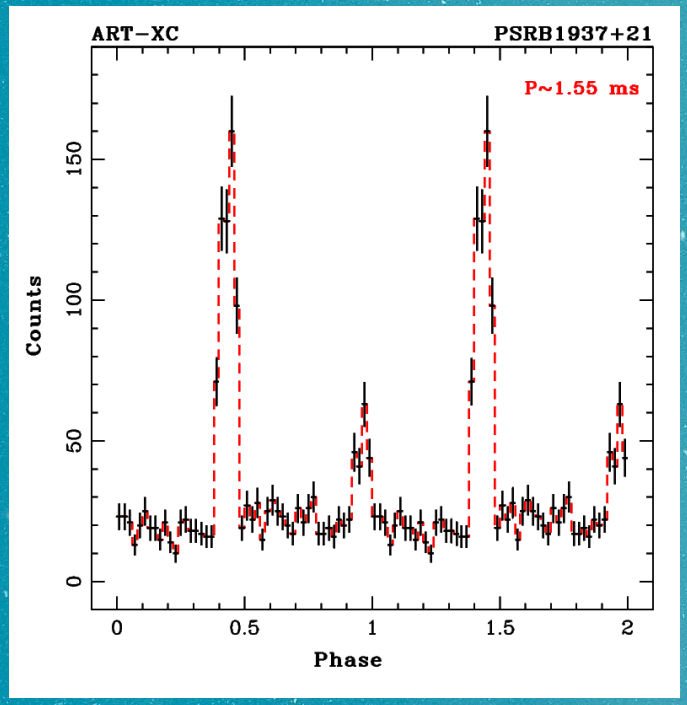




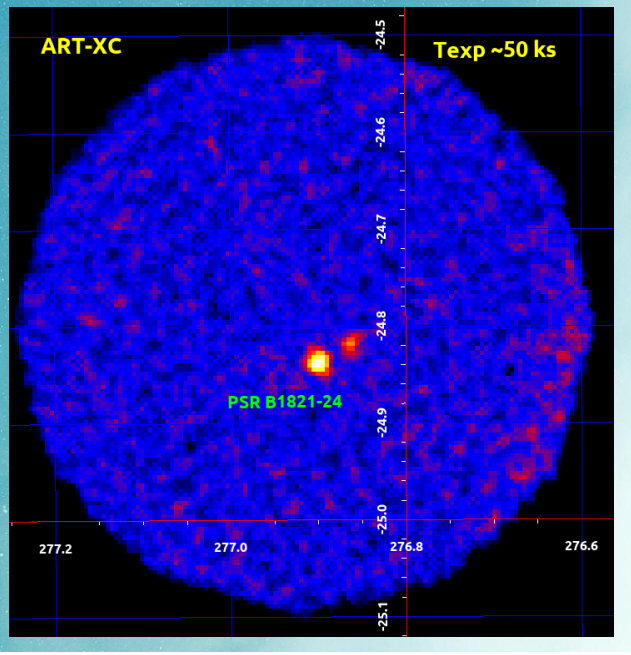
dP/dt=1.47E-13 s/s

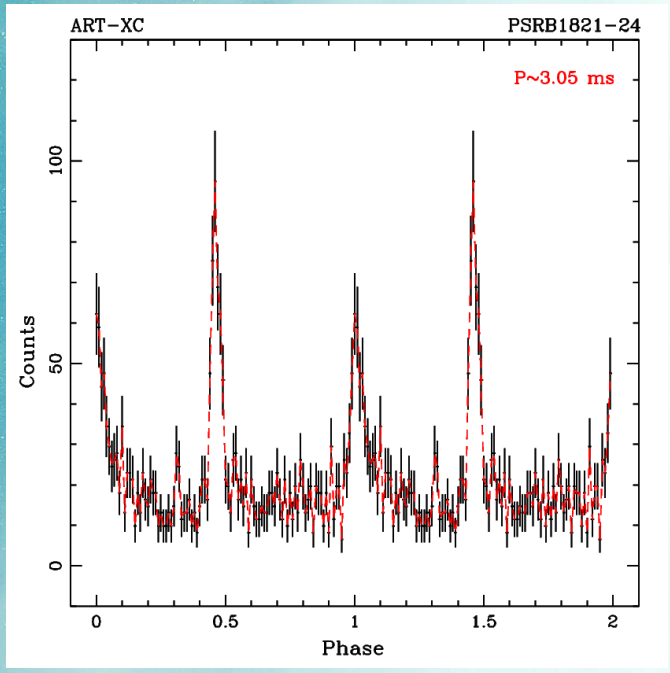
PSR B1937+21



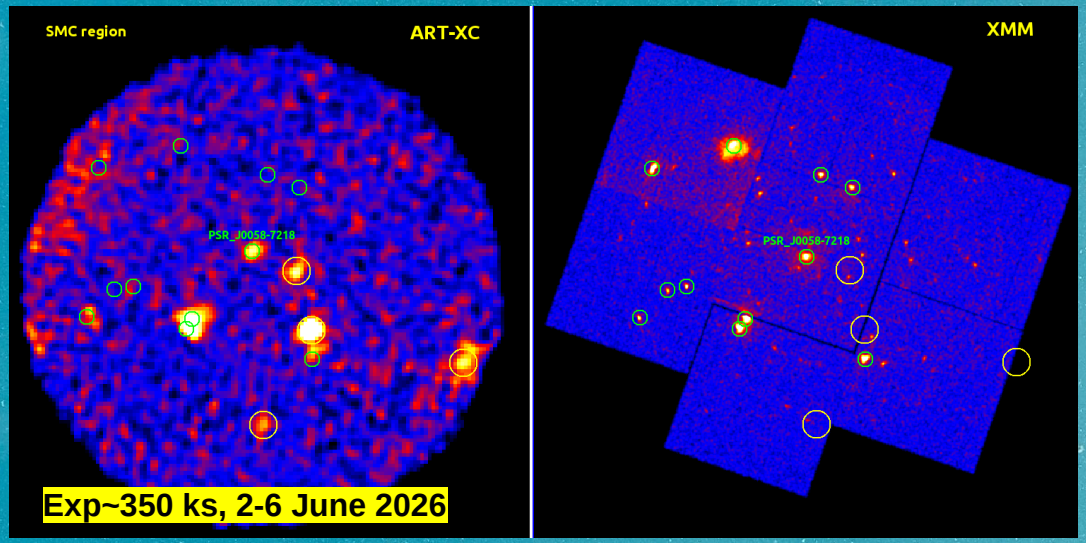


PSR B1821-24





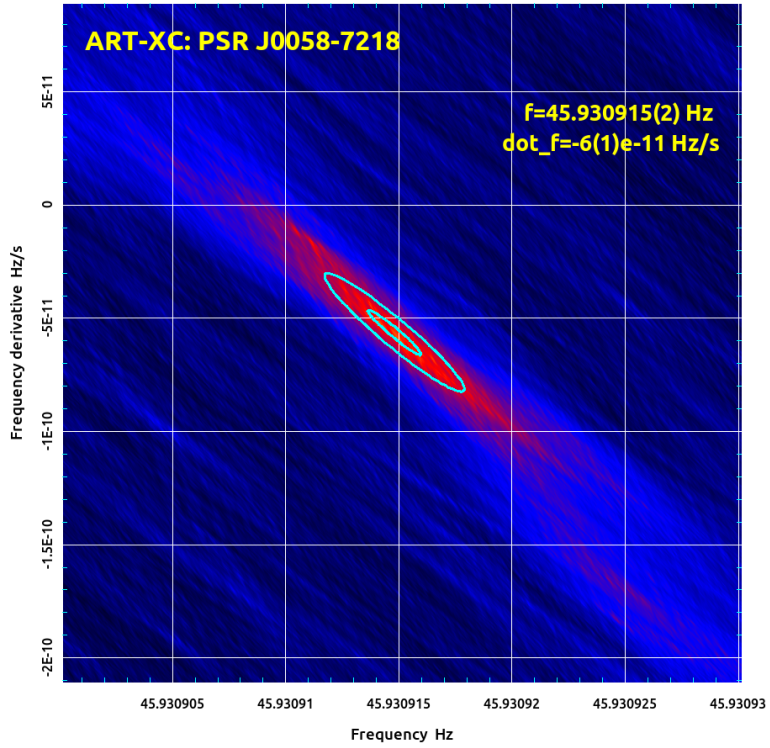
PSR J0058-7218 : 22ms puls. discovery Maitra et al. 2021 (XMM)

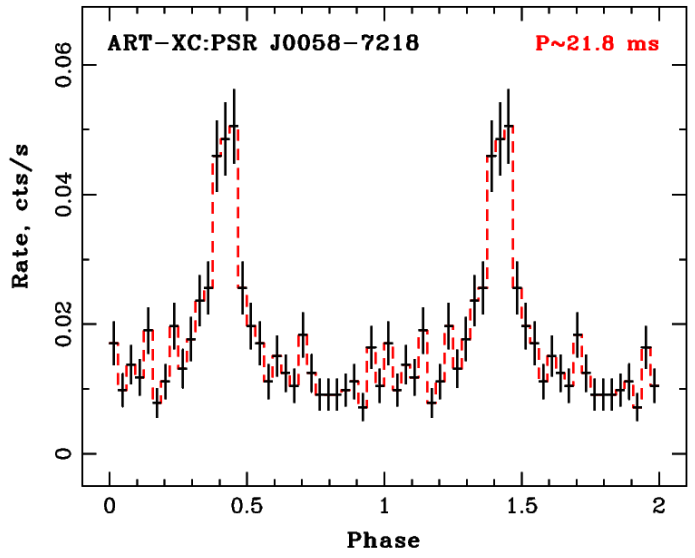


Parameter	Value
Range (MJD)	58924.016–58925.583
Epoch (MJD)	58924.0
Frequency, ν (Hz)	45.9429870(4)
Frequency derivative, $\dot{\nu}$ (Hz s^{-1})	$-6.1(6) \times 10^{-11}$
Period, P (ms)	21.7661076(2)
Period derivative, $\dot{P}$ (s s^{-1})	$2.9(3) \times 10^{-14}$

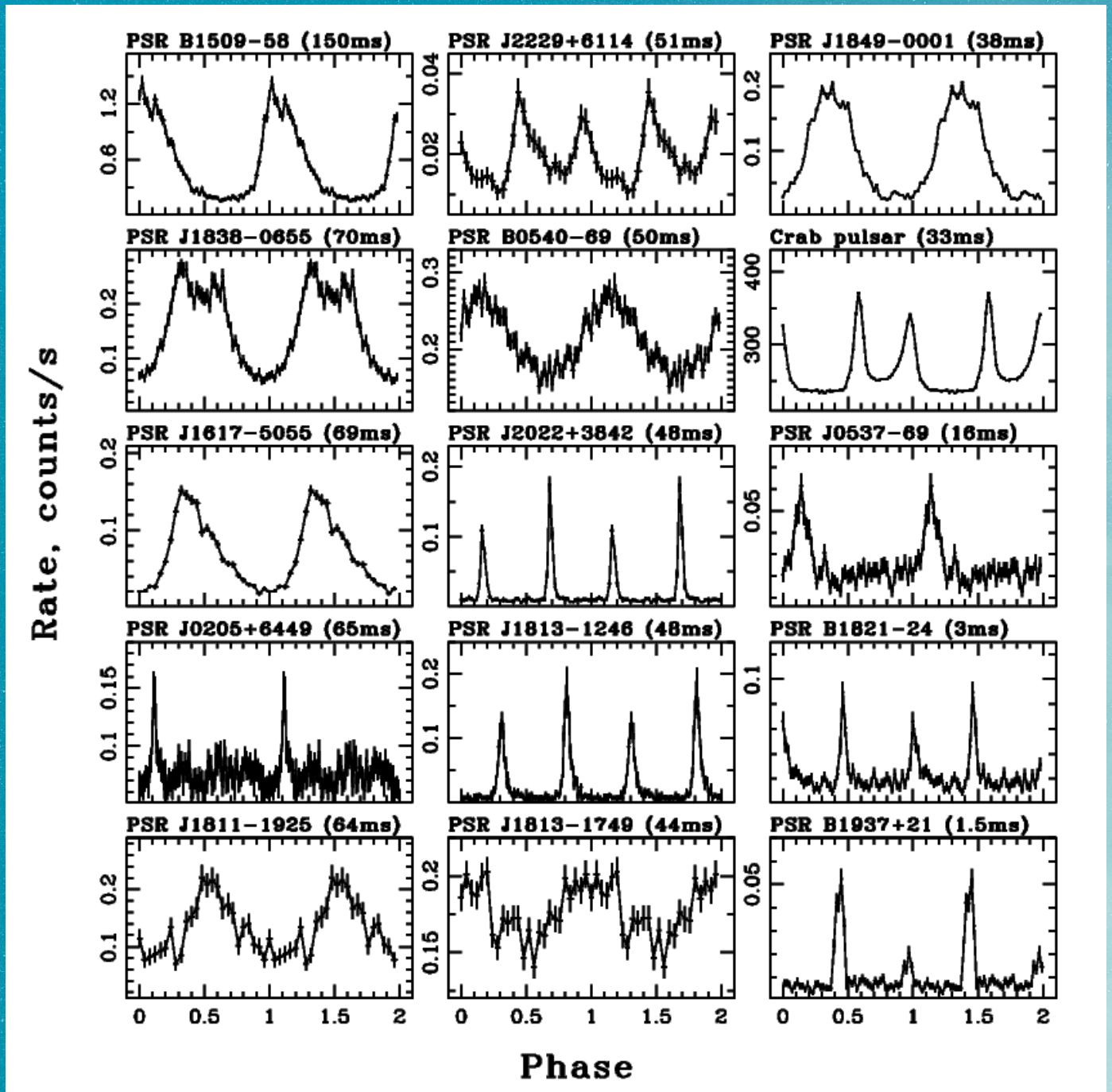
ART-XC:

Range (MJD)	61193.3 – 61197.3
Frequency (Hz)	45.930915(2)
Frequency derivative (Hz/s)	-6(1)e-11
Period (ms)	21.771828408(9)
Period derivative (s/s)	2.8(6)e-14

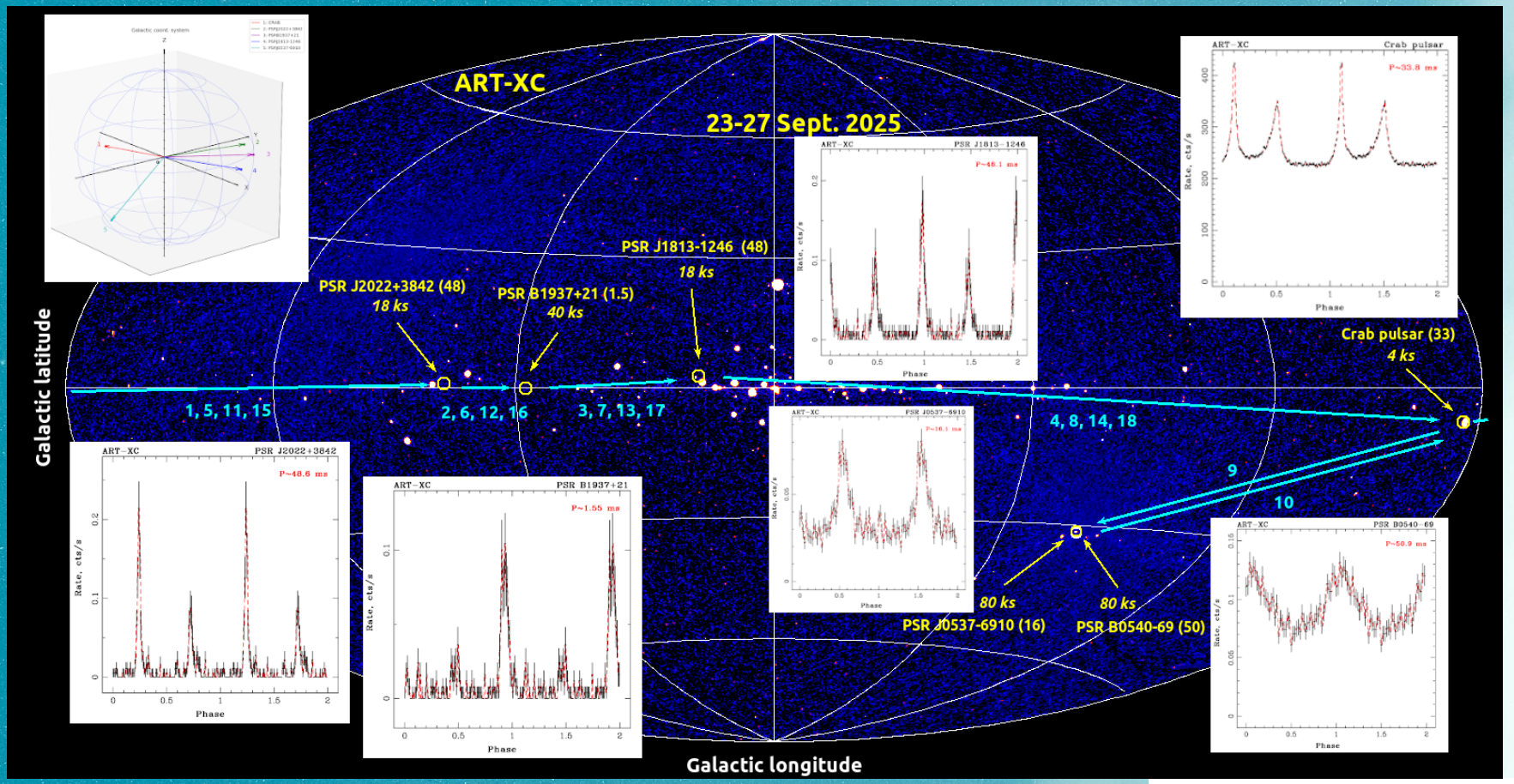


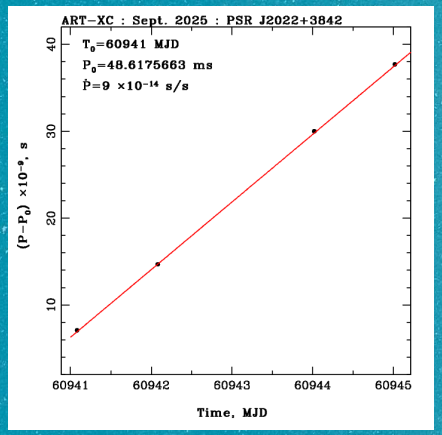


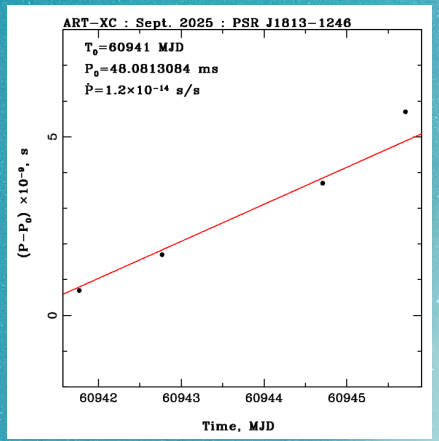
Long term period derivative:
dotPlong=(Partxc-Pxmm)/dT
~2.9-14 s/s

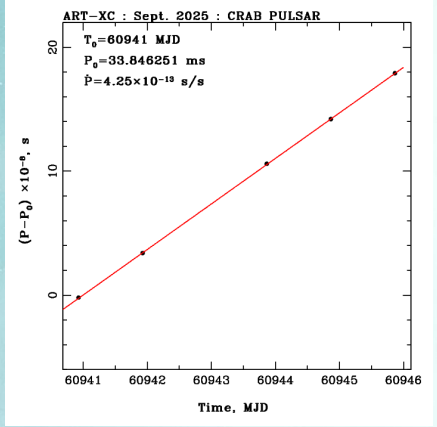

PSR B1509−58 (150ms)
PSR J2229+6114 (51ms)
PSR J1849−0001 (38ms)
PSR J1838−0655 (70ms)
PSR B0540−69 (50ms)
Crab pulsar (33ms)
PSR J1617−5055 (69ms)
PSR J2022+3842 (48ms)
PSR J0537−69 (16ms)
PSR J0205+6449 (65ms)
PSR J1813−1246 (48ms)
PSR B1821−24 (3ms)
PSR J1811−1925 (64ms)
PSR J1813−1749 (44ms)
PSR B1937+21 (1.5ms)
Rate, counts/s
Phase

ART-XC program of RP pulsars monitoring







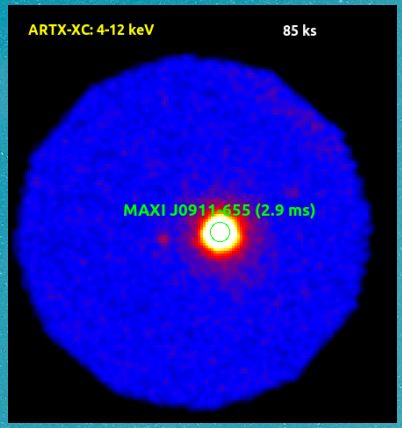


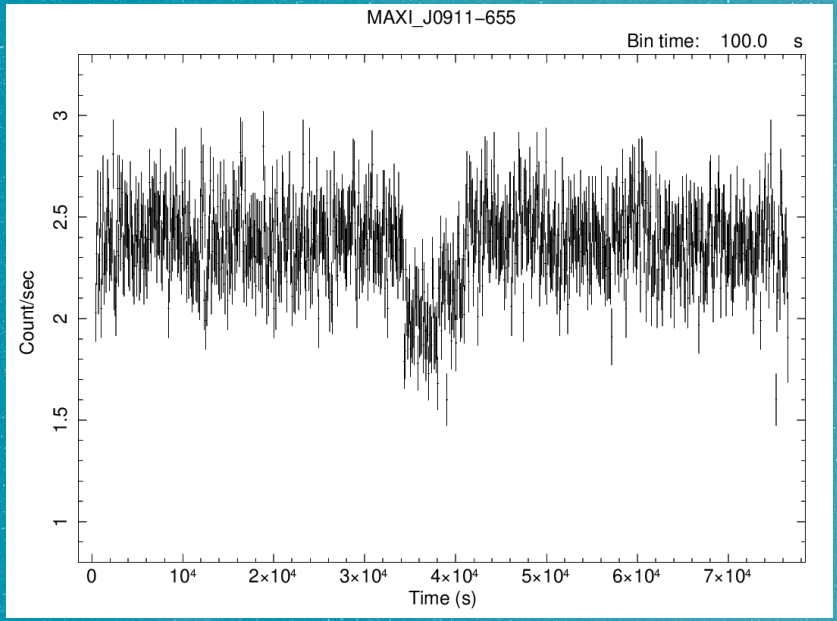
Accretion powered X-ray millisecond pulsars

Source	$\nu_s(P)$ Hz (ms)	P_{orb} (hr)	$a_x sini$ lt-s	f_x ($M_\odot$)	M_2, min ($M_\odot$)	bsts/ b.osc	year	Comp. Type
XSS J12270–4859 (t)	593 (1.7)	6.91		3.9×10^{-3}	0.27	n		MS
PSR J1023+0038 (t)	592 (1.7)	4.75		1.1×10^{-3}	0.20	n		MS
Aql X-1 (i)	550 (1.8)	18.95		1.4×10^{-2}	0.56	y/y		MS
MAXI J1816-195	528 (1.89)	4.83	0.2629	4.8×10^{-3}	0.10	y/n		MS
IGR J17591-2342	527 (1.9)	8.80	1.2277	1.5×10^{-2}	0.37	n/n		MS
Swift J1749.4–2807 (eclips)	518 (1.9)	8.82	1.8999	5.5×10^{-2}	0.59	y/n		MS
SRGA J144459.2-604207	448 (2.2)	5.22	0.6513	6.3×10^{-3}	0.25	y/y	2024	MS
SAX J1748.9–2021 (i)	442 (2.3)	8.77	0.39	4.8×10^{-4}	0.10	y/n		MS
IGR J17498–2921	400.99 (2.5)	3.84	0.3651	2.0×10^{-3}	0.17	y/y	2011	MS
XTE J1814–338	314 (3.2)	4.27	0.390	2.0×10^{-3}	0.17	y/y	2003	MS
IGR J18245–2452 (t)	254 (3.9)	11.03	0.7659	2.3×10^{-3}	0.17	y/y	2013	MS
IGR J17511–3057	245 (4.1)	3.47	0.2752	1.1×10^{-3}	0.13	y/y	2009	MS
IGR J00291+5934	599 (1.7)	2.46	0.065	2.8×10^{-5}	0.039	n		BD
IGR J17379-3747	468 (2.1)	1.88	0.0770	8.0×10^{-5}	0.056	n	2004	BD
SAX J1808.4–3658	401 (2.5)	2.01	0.0628	3.8×10^{-5}	0.043	y/y	1998	BD
HETE J1900.1–2455 (i)	377 (2.7)	1.39	0.0184	2.0×10^{-6}	0.016	y/y	2006	BD
XTE J1751-305	435 (2.3)	0.71	0.0101	1.3×10^{-6}	0.014	n	2002	He WD
MAXI J0911–655	339.97 (2.9)	0.74	0.0175	6.2×10^{-6}	0.024	n		He WD?
MAXI J1957+031	313.64 (3.2)	1.015	0.0138	1.6×10^{-6}	0.017	n	2022	He WD?
NGC6440 X–2	206 (4.8)	0.95		1.6×10^{-7}	0.0067	n		He WD
Swift J1756.9–2508	182 (5.5)	0.91		1.6×10^{-7}	0.007	n		He WD
IGR J17062–6143	164 (6.1)	0.63		0.91×10^{-7}	0.006	n		He WD?
IGR J16597–3704	105 (9.5)	0.77		1.2×10^{-7}	0.006	n		He WD
XTE J0929–314	185 (5.4)	0.73		2.9×10^{-7}	0.0083	n		C/O WD
XTE J1807–294	190 (5.3)	0.67		1.5×10^{-7}	0.0066	n		C/O WD

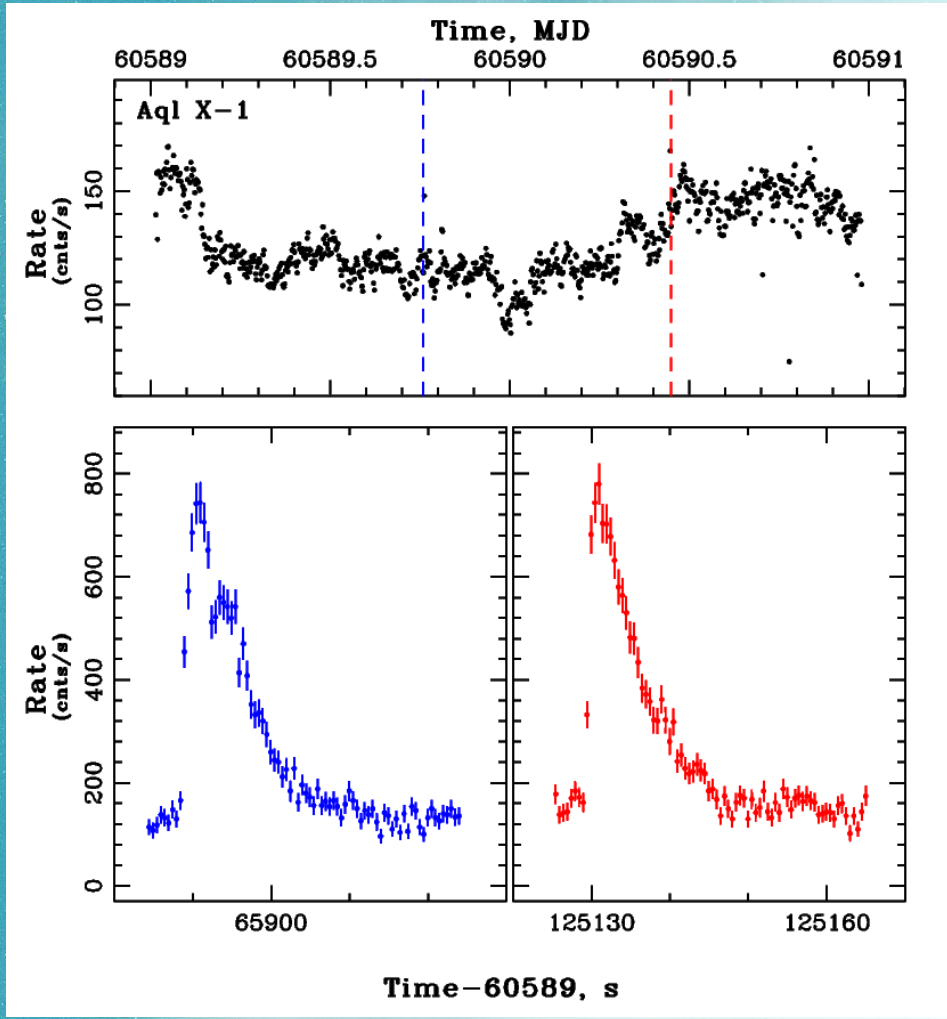
ART-XC: 8-9 July 2021

NICER:
No pulsations
Ng et al. 2021
Atel14767
(8 July)



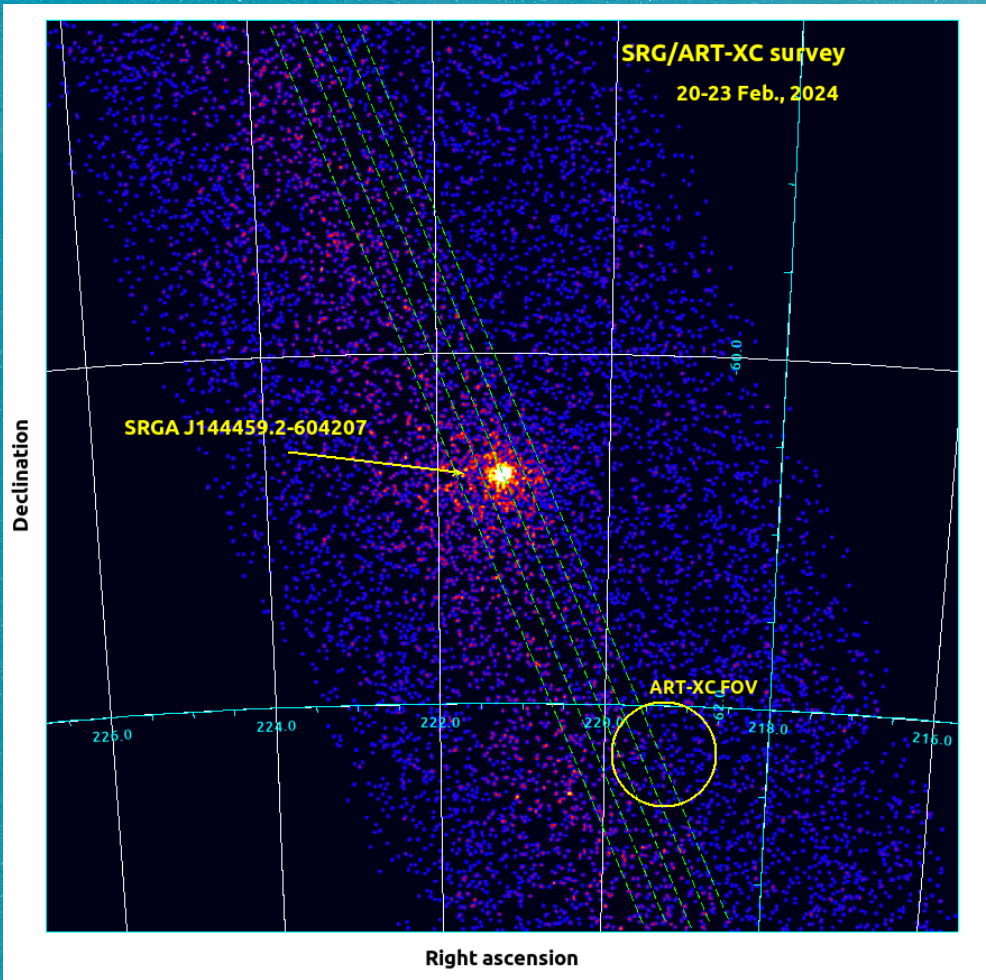


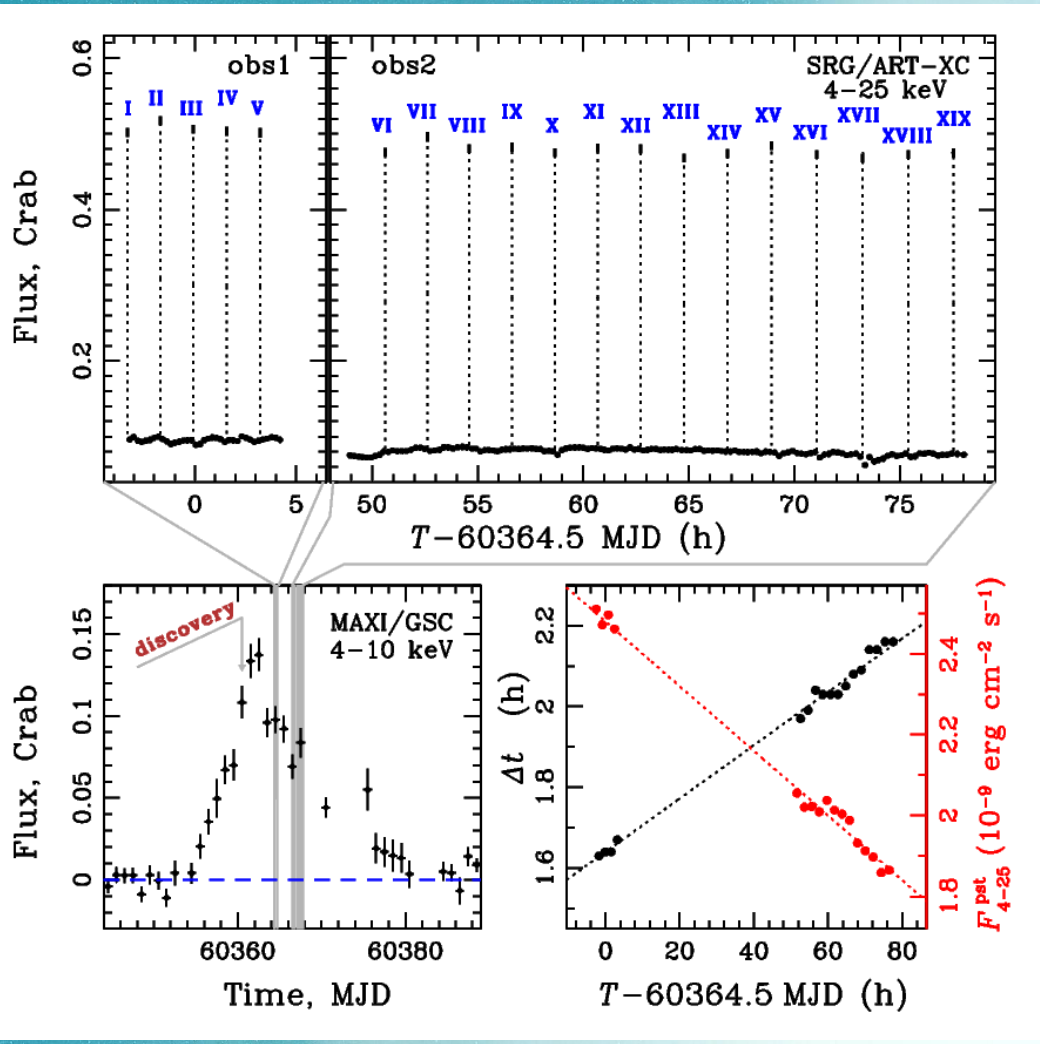
ART-XC: 6-8 Oct. 2024

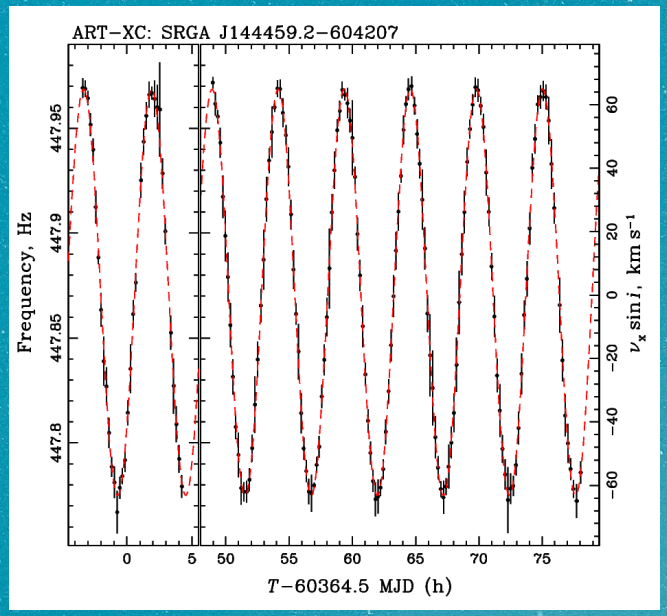


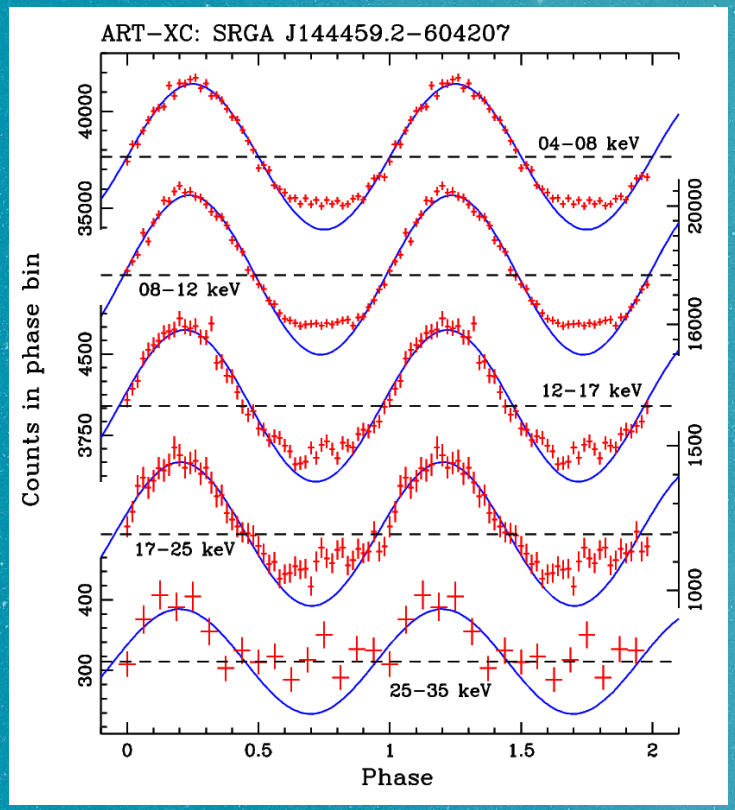
ATEL #16464 ATEL #16464

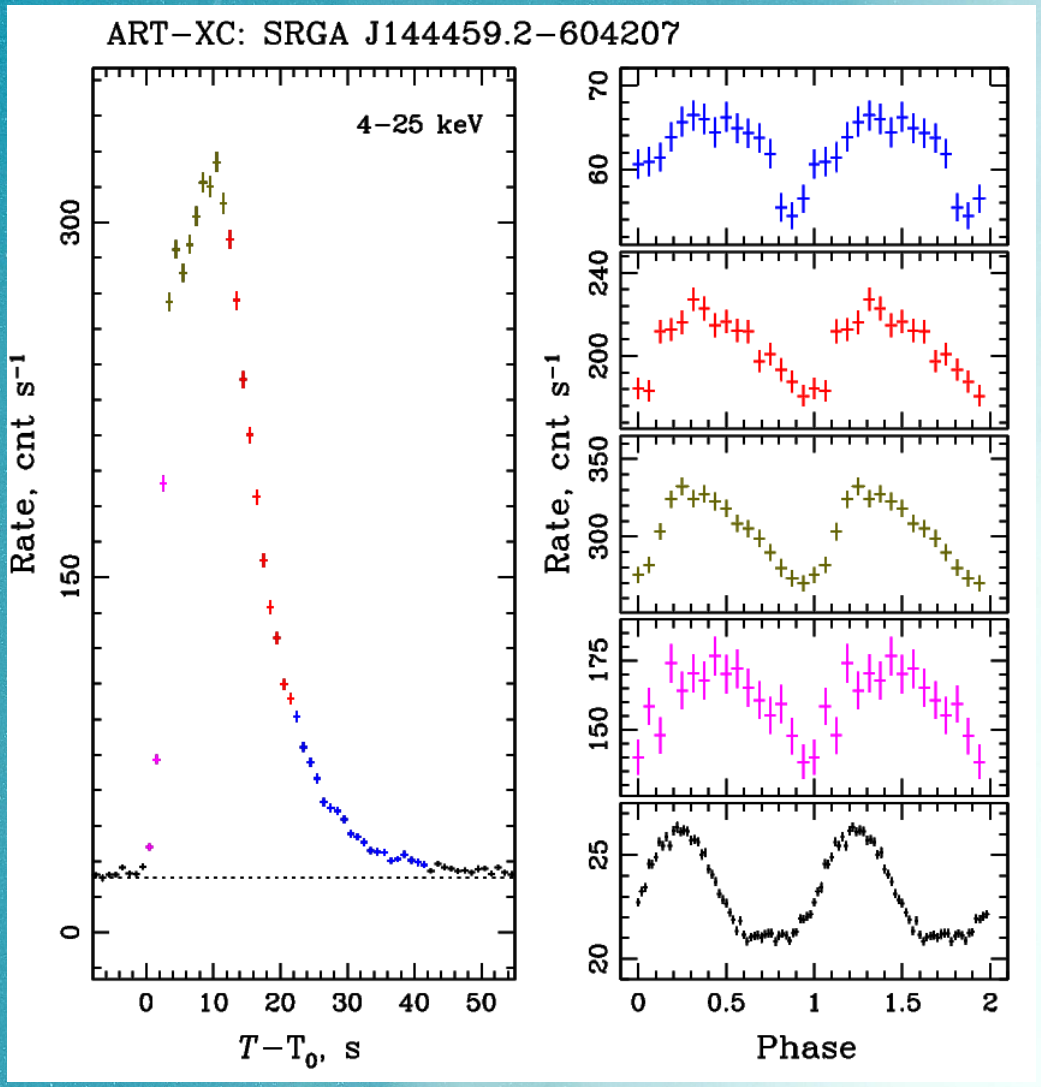
Title: SRG/ART-XC discovery of new bright Galactic X-ray transient
SRGA J144459.2-604207
Author: I. A. Mereminskiy, A. N. Semena, S. V. Molkov, A. A. Lutovinov,
A. Yu. Tkachenko, V. A. Arefiev (IKI RAS, Moscow)
Queries: i.a.mereminskiy@gmail.com
Posted: 21 Feb 2024; 15:39 UT
Subjects:X-ray, Request for Observations, Transient









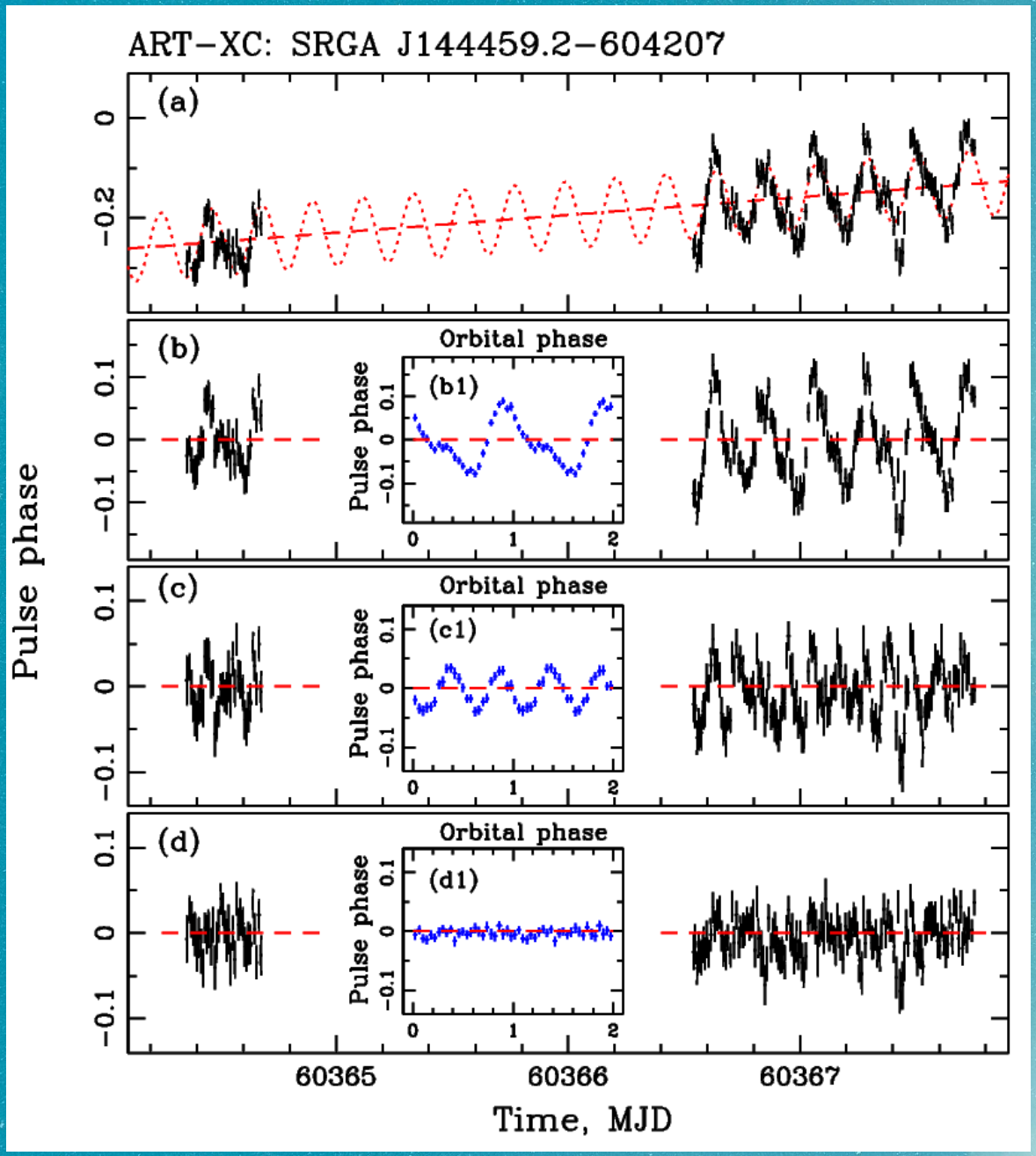


Molkov et al. 2024 (ART-XC)

Ng et al. 2024 (NICER)

Papitto et al. 2024 (IXPE, NICER, XMM, NuSTAR)

Li et al. 2025 (NICER, EP, IXPE, NuSTAR, HXMT, INTEGRAL)



NICER timing model
Ng et al. 2024

Ecc=0.000226(44)

Molkov et al. 2026 (in preparation)

Discovery:
Negoro et al. 2015 (MAXI),
Cherepaschuk et al. 2015 (INTEGRAL)

3.2 ms pulsations:
Sanna et al. 2022 (NICER)

Table 1. Orbital parameters and spin frequency of MAXI J1957+032 with uncertainties on the last digit quoted at 1σ confidence level. T_0 represents the reference epoch for this timing solution.

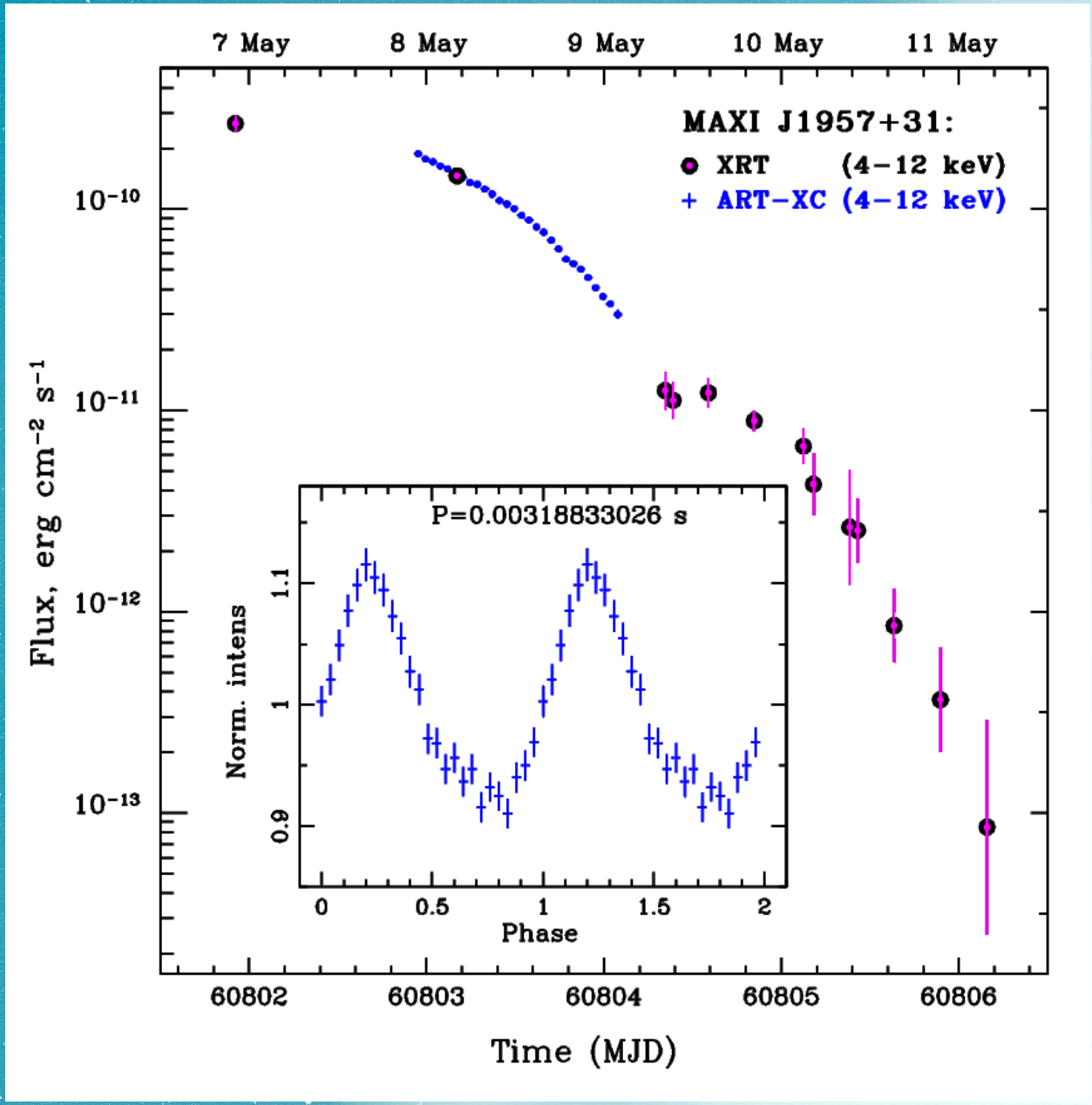
Parameters	
RA (J2000)	$19^h56^m39.11^s \pm 0.04^s$
Dec. (J2000)	$03°26'43.7'' \pm 0.6''$
P_{orb} (s)	3653.046(61)
x (lt-s)	0.013796(25)
T_{ASC} (MJD/TDB)	59749.633146(18)
Eccentricity	$<1.4 \times 10^{-2}$ (3σ c.l.)
ν_0 (Hz)	313.64374049(22)
T_0 (MJD/TDB)	59749.0
χ^2_{red}/d.o.f	1.23/23

Outburst 2025

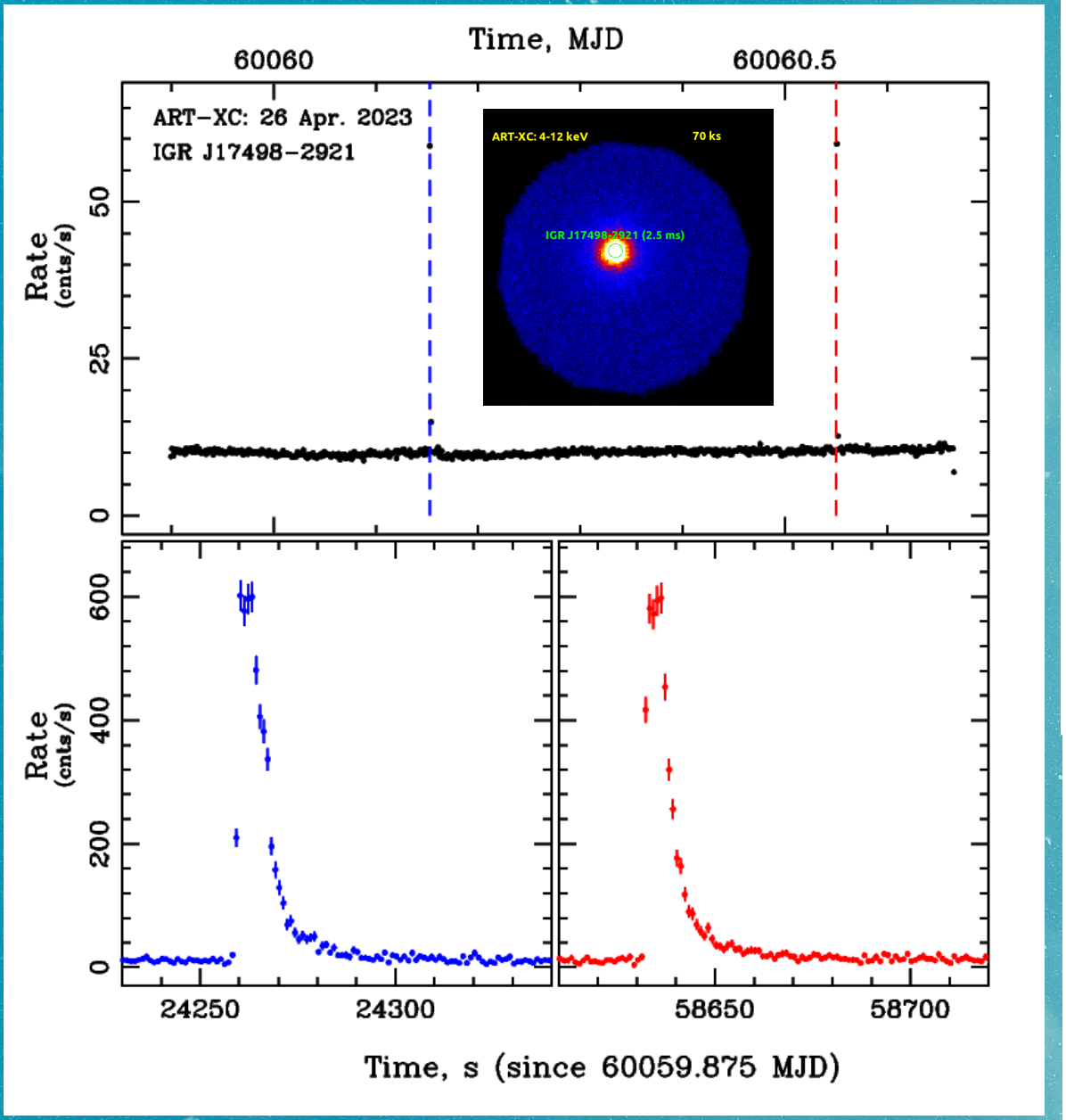
7 May,
Outburst detection by EP-WXT
Sun et al. 2025,
GCN 40375 (7 May)

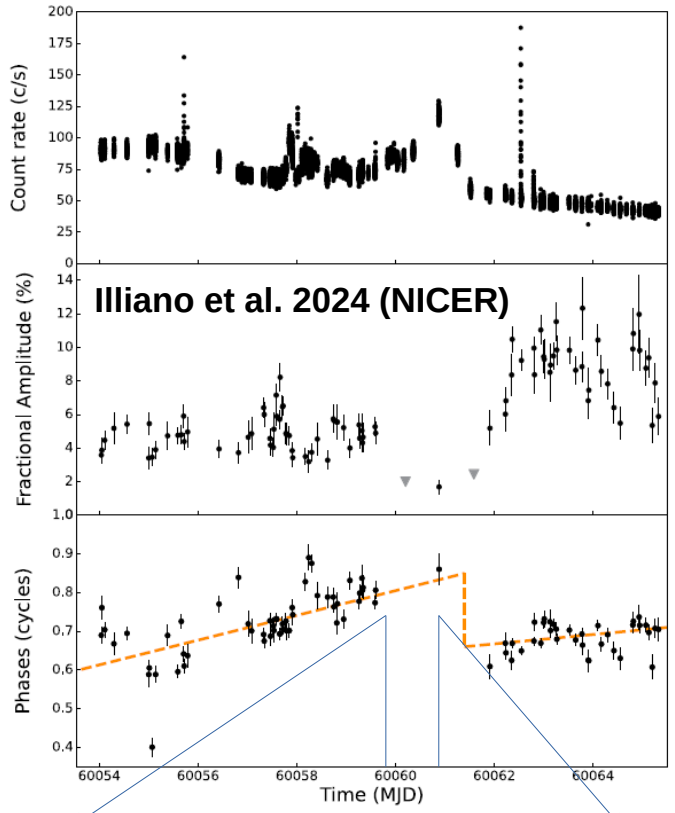
7 May
Outburst confirmation by MAXI
Negoro et al. 2025 (MAXI),
Atel.17170 (7 May)

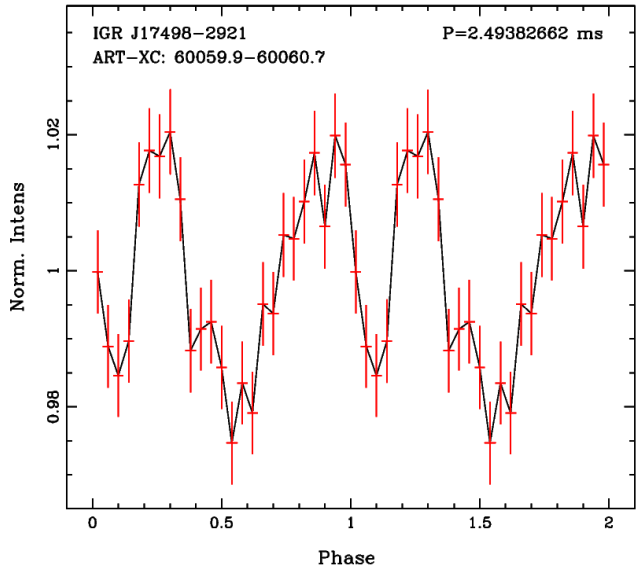
7-10 May,
Detection of pulsations EP (P=0.003188330843(7))
Li et al. 2025,
Atel. 17279 (9 July)



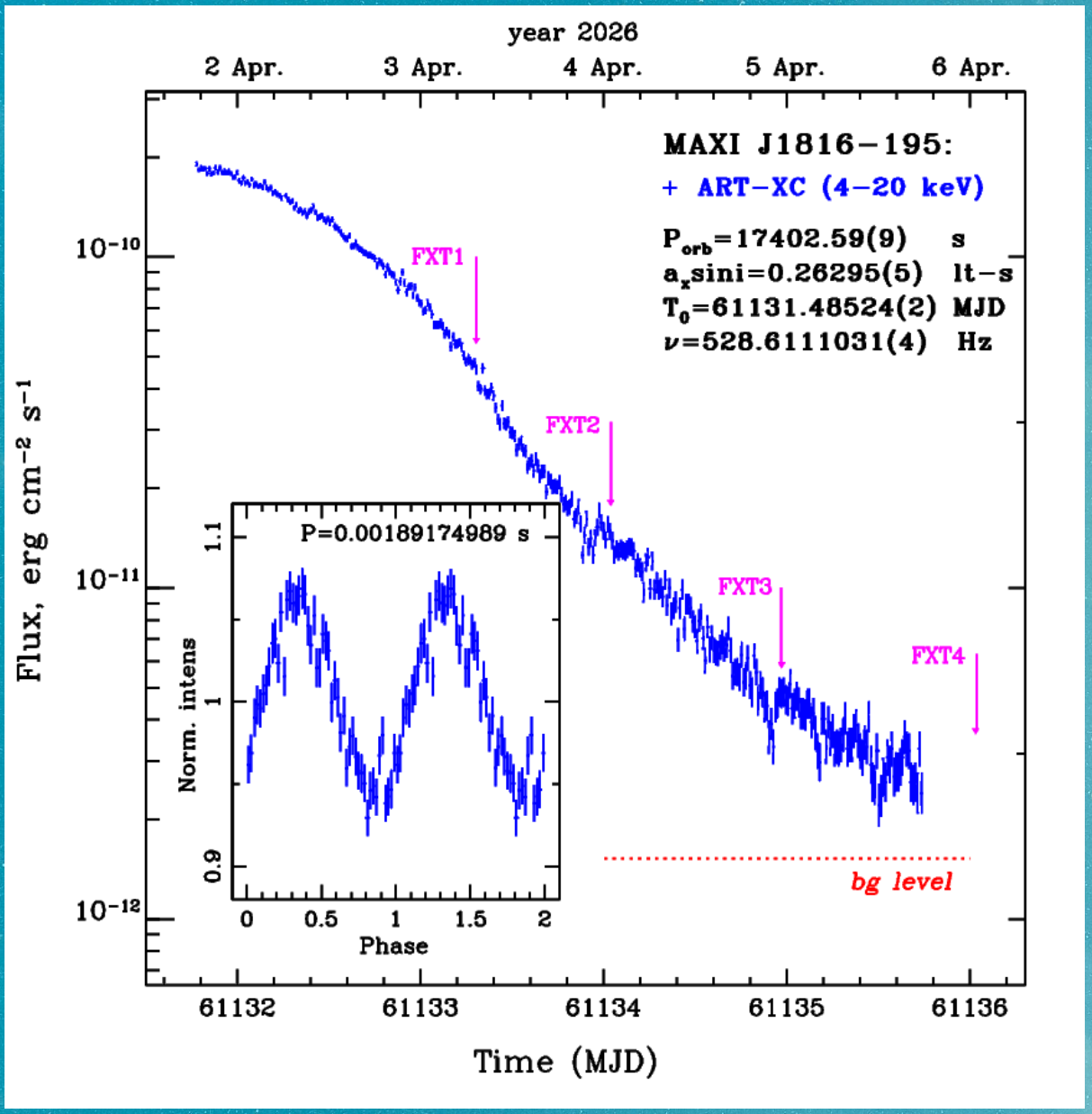
Molkov et al. 2026 (in preparation)

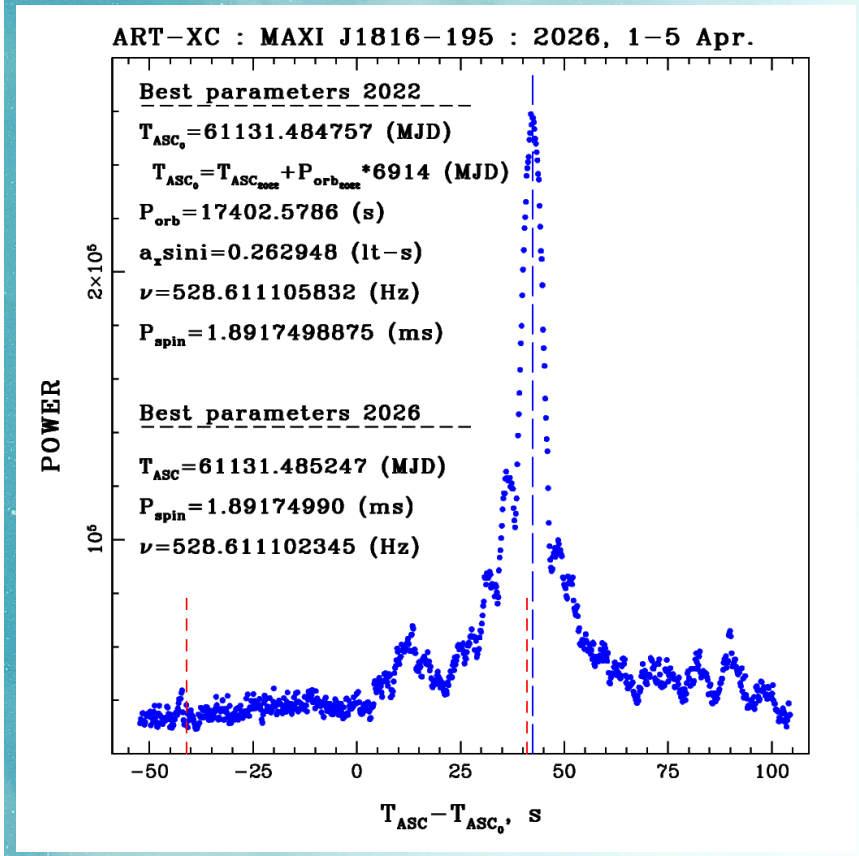






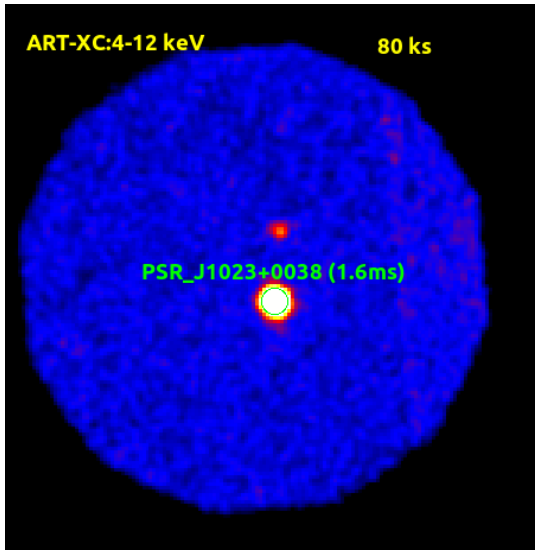
Chelovekov et al. 2026 (in preparation)

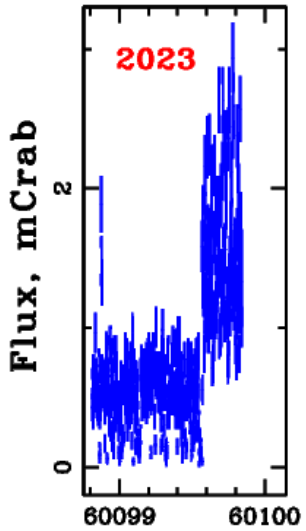


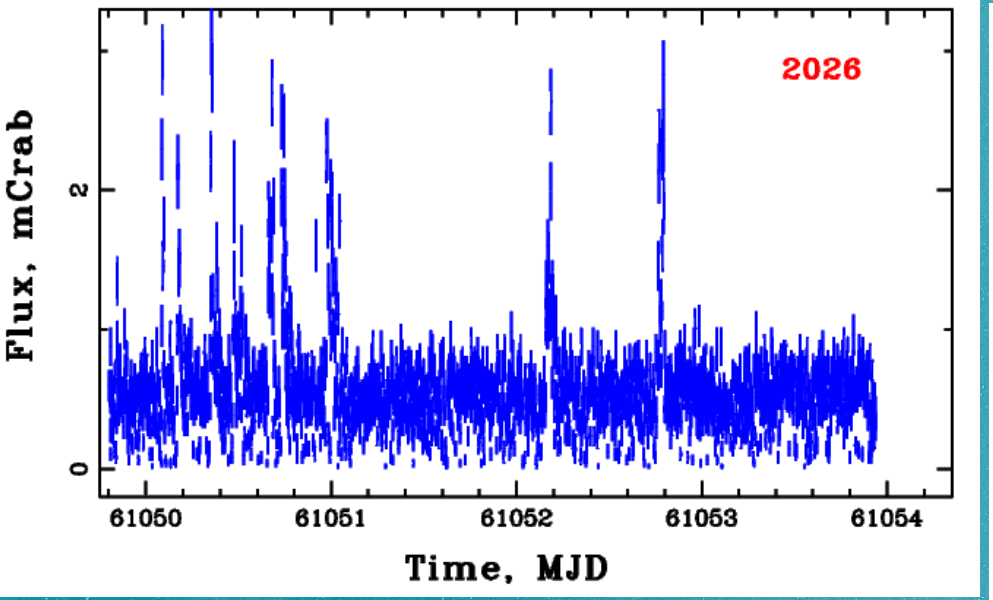


Li et al. 2026 in preparation

Transitional pulsar PSR J1023+0038







Illiano et al. (2023)

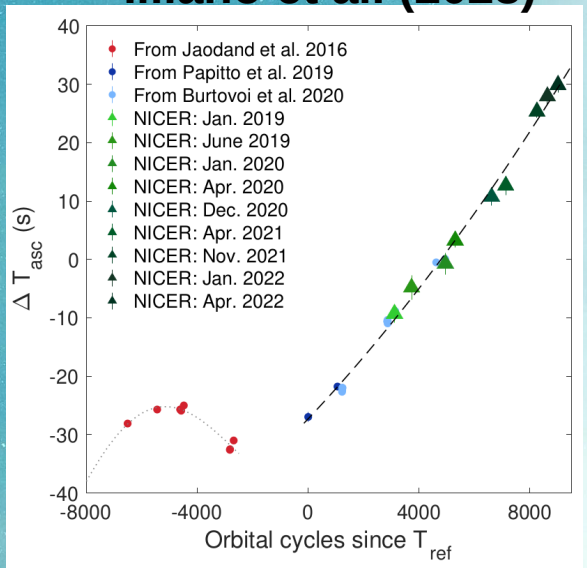
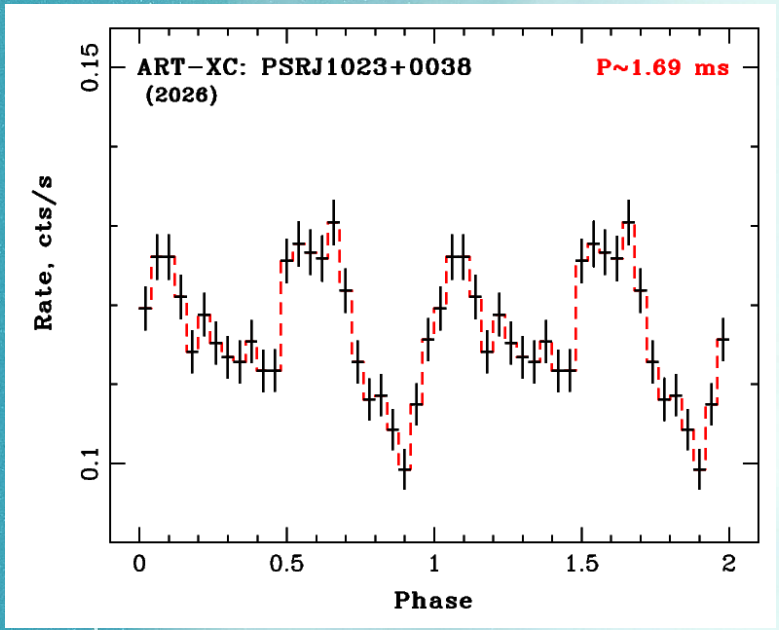


Fig. 1. Long-term evolution of T_{asc} as a function of the number of orbital cycles since T_{ref} = 57897.027668 MJD. Red points are the values



Conclusions:

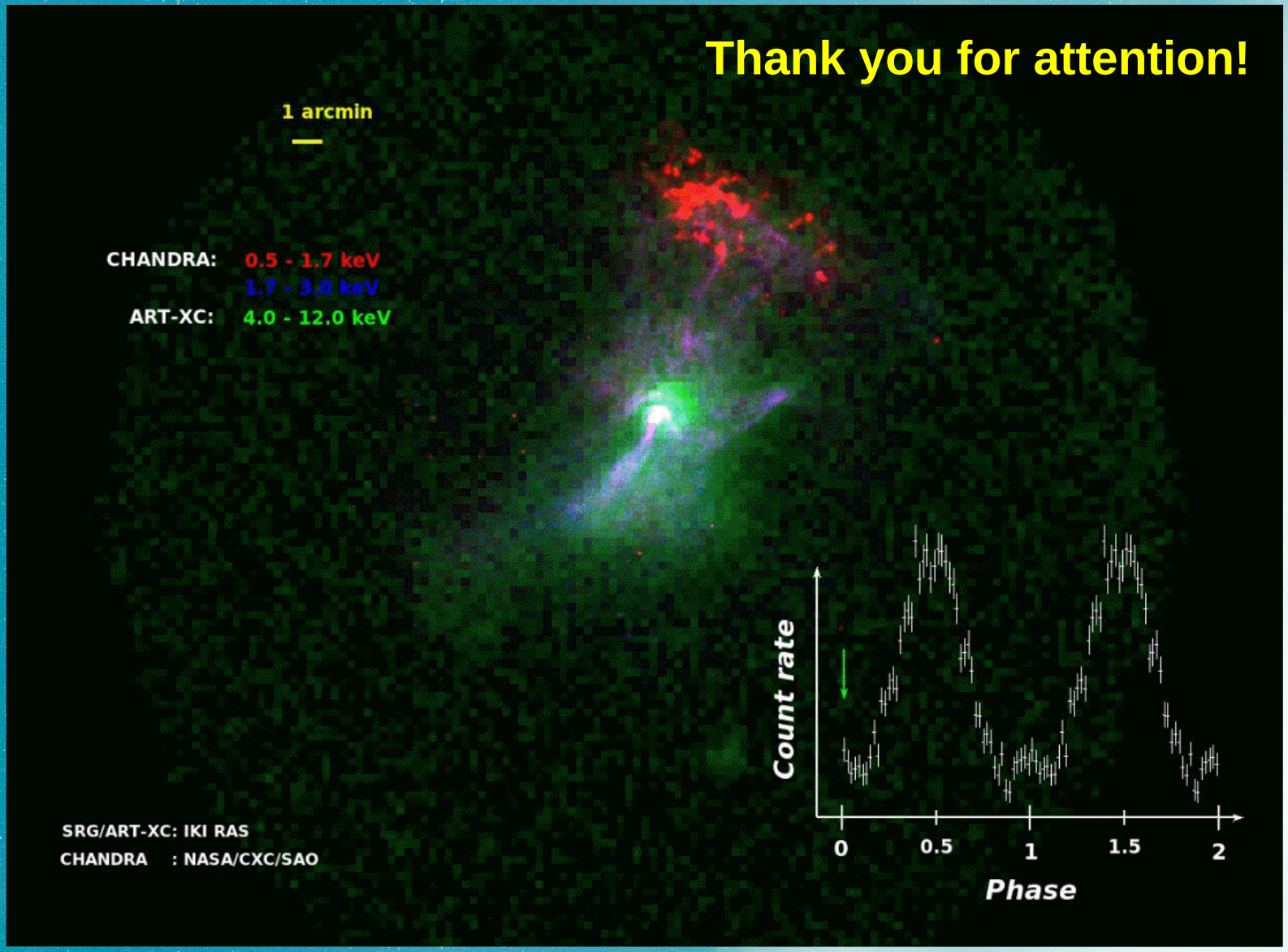
1) ART-XC is well suit for the fast timing:
   a) relative timing accuracy – systematic frequency uncertainty <1e-9 Hz
   b) absolute timing accuracy – few tens of milliseconds

2) ART-XC executes program of timing behavior monitoring of two dozens rotation-powered X-ray pulsars;

3) ART-XC has TOO program on Accreating millisecond X-ray pulsars

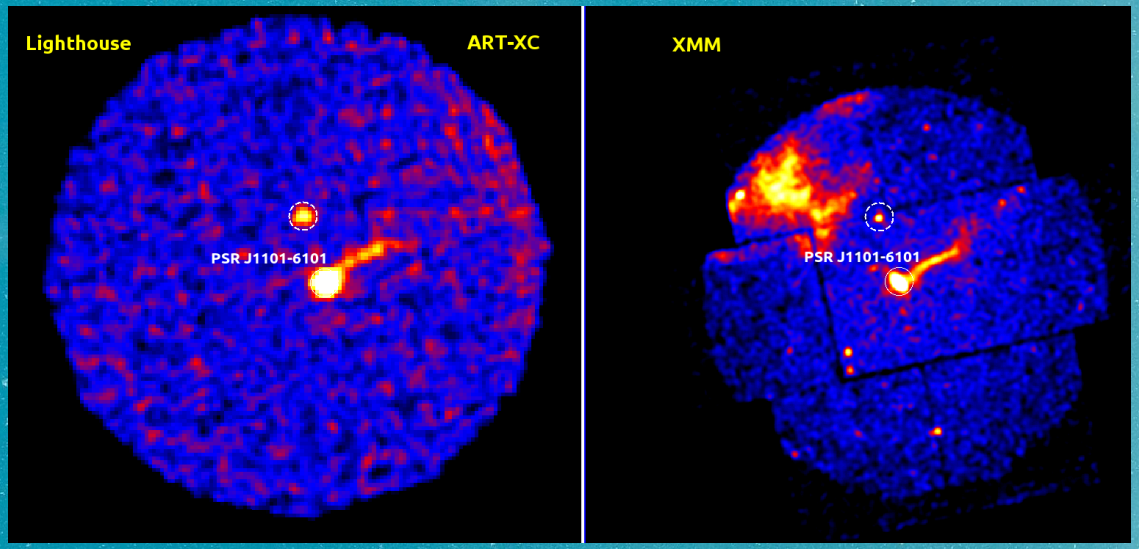
HEACOSS-2026

15-19 June 2026, Erevan



PSR J1101-6101 :

63ms puls. discovery Halpern et al. 2014 (XMM)



PSR J2021+3651 :

104ms Radio-, Gamma- pulsar, no x-ray pulsations