The new ULX pulsar in NGC 300 and its fast period evolution

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The discovery of ultraluminous X-ray pulsars

- M 82 X2 (Bacchetti+ 2014)
  spin period P = 1.37s, 2.5d modulation in NuSTAR data
  $\dot{P} = -2\mathrm{x}10^{-10}$ s s^{-1} (over 5 years)
  $L_{X,max} \sim 2\mathrm{x}10^{40}$ erg/s, can vary by factor 100

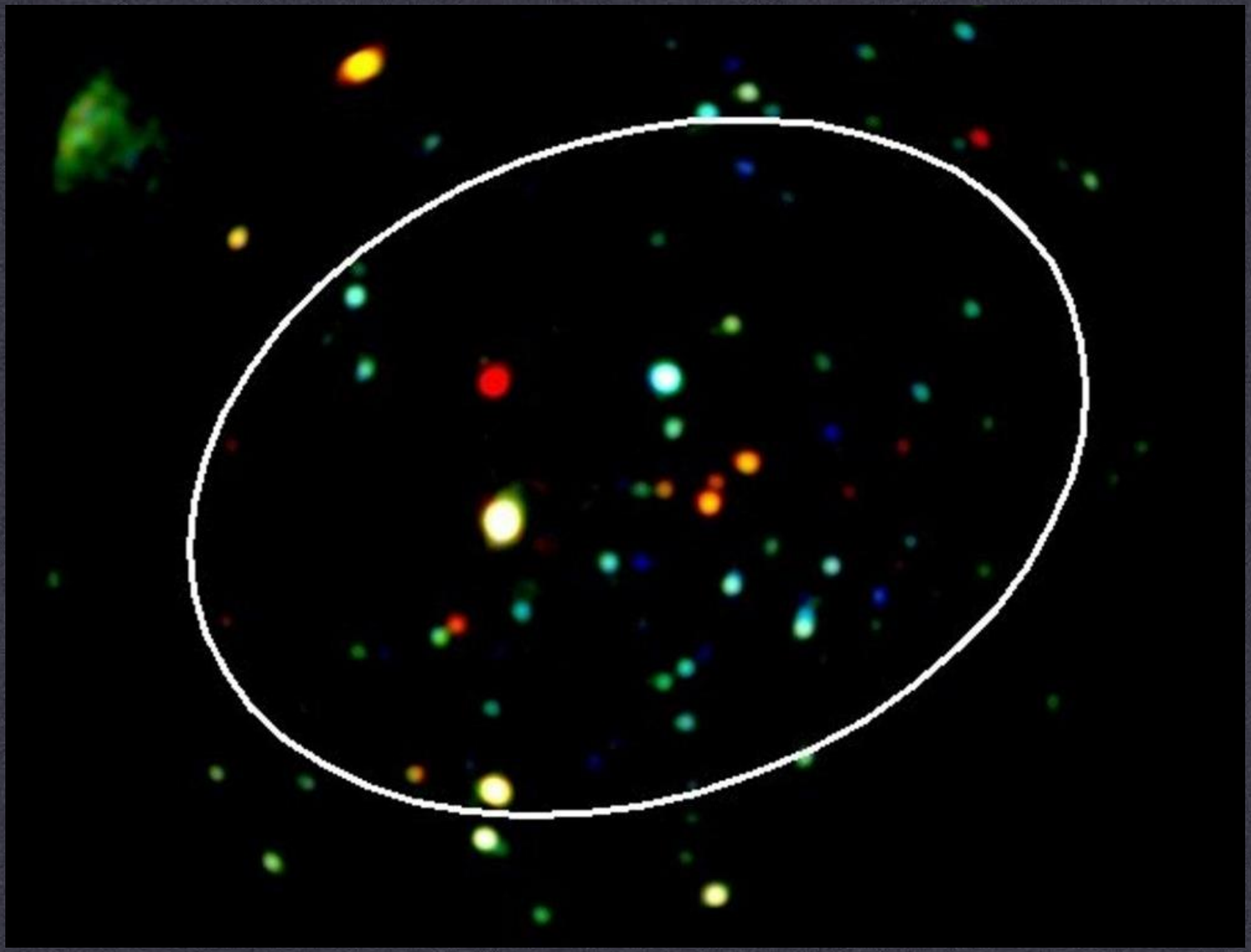
- NGC 7793 P13 (Fürst+ 2016; Israel+ 2017b)
  P = 0.42s
  $\dot{P} = -3.5\mathrm{x}10^{-11}$ s s^{-1} (over 3 years)
  $L_{X,max} \sim 10^{40}$ erg/s, can vary by factor ~1000

- NGC 5907 ULX1 (Israel+ 2017a)
  P = 1.136s in 2013; 1.428s in 2003; P_{orb} = 5.3d
  $\dot{P} = -8.1\mathrm{x}10^{-10}$ s s^{-1} $L_{bol,max} \sim 2\mathrm{x}10^{41}$ erg/s

- NGC 300 ULX1 [Carpano+ 2018 (CHMV18), Vasilopoulos+2018 submitted (VHCM18)]
  at discovery:
  P = 31.71s to 31.54s in Dec 2016
  $\dot{P} = -5.56\mathrm{x}10^{-7}$ s s^{-1} (over ~4 days)

  over 3.5 years:
  126.3s to 19.05s from Nov 2014 to Apr 2018
  $-1.15\mathrm{x}10^{-5}$ s s^{-1} to $-1.51\mathrm{x}10^{-7}$ s s^{-1}

The spiral galaxy NGC 300

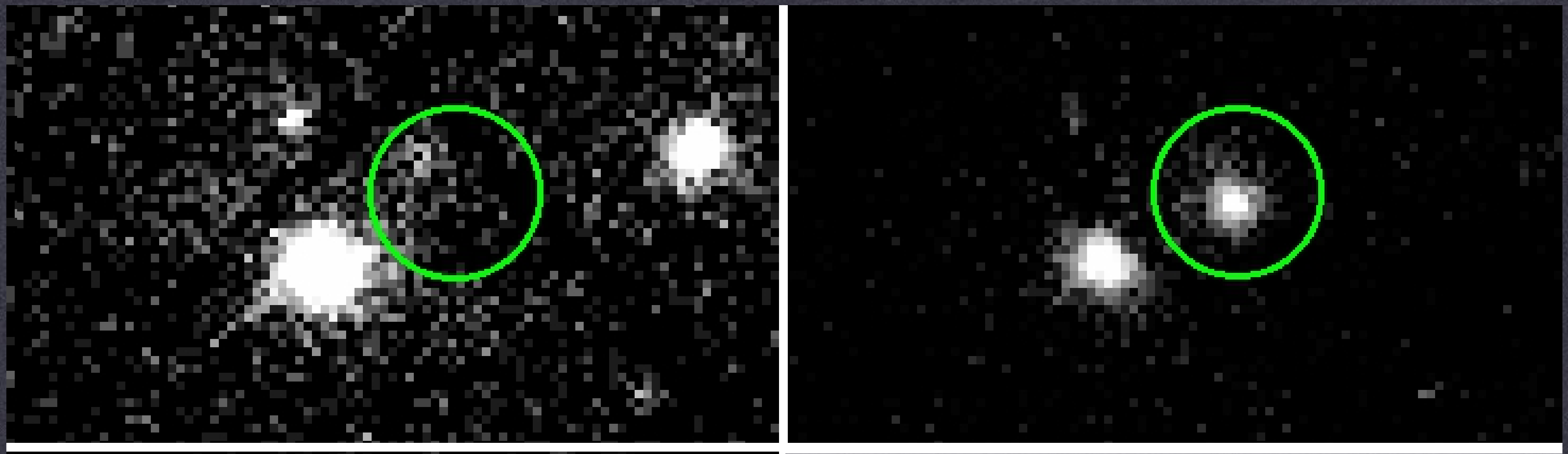


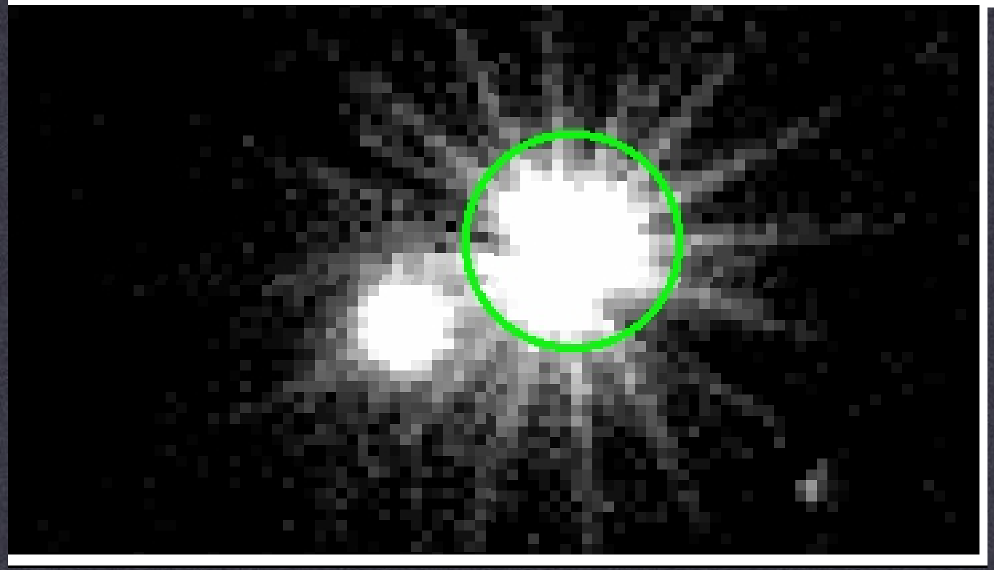
- NGC 300 is a nearby almost face-on spiral galaxy, located at 1.88 Mpc distance
- X-ray source population studied with ROSAT and XMM-Newton (Carpano+ 2005, +PhD)
- NGC 300 X-1: So far the brightest, but persistent X-ray source.
  Wolf-Rayet/black hole X-ray binary, with $L_X \sim 2 \times 10^{38}$ erg/s (Carpano+ 2007)

XMM/NuSTAR observations in Dec 2016

- Simultaneous XMM-Newton and NuSTAR observations of NGC 300
- 16-20 December 2016, timespan 310ks
- Target: NGC 300 X-1

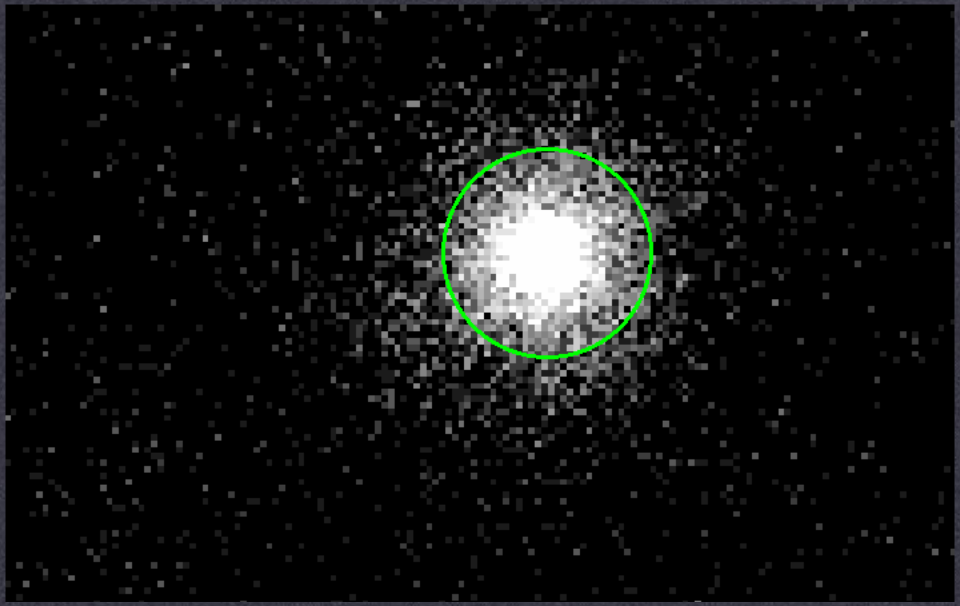
May 2005 XMM-Newton May 2010





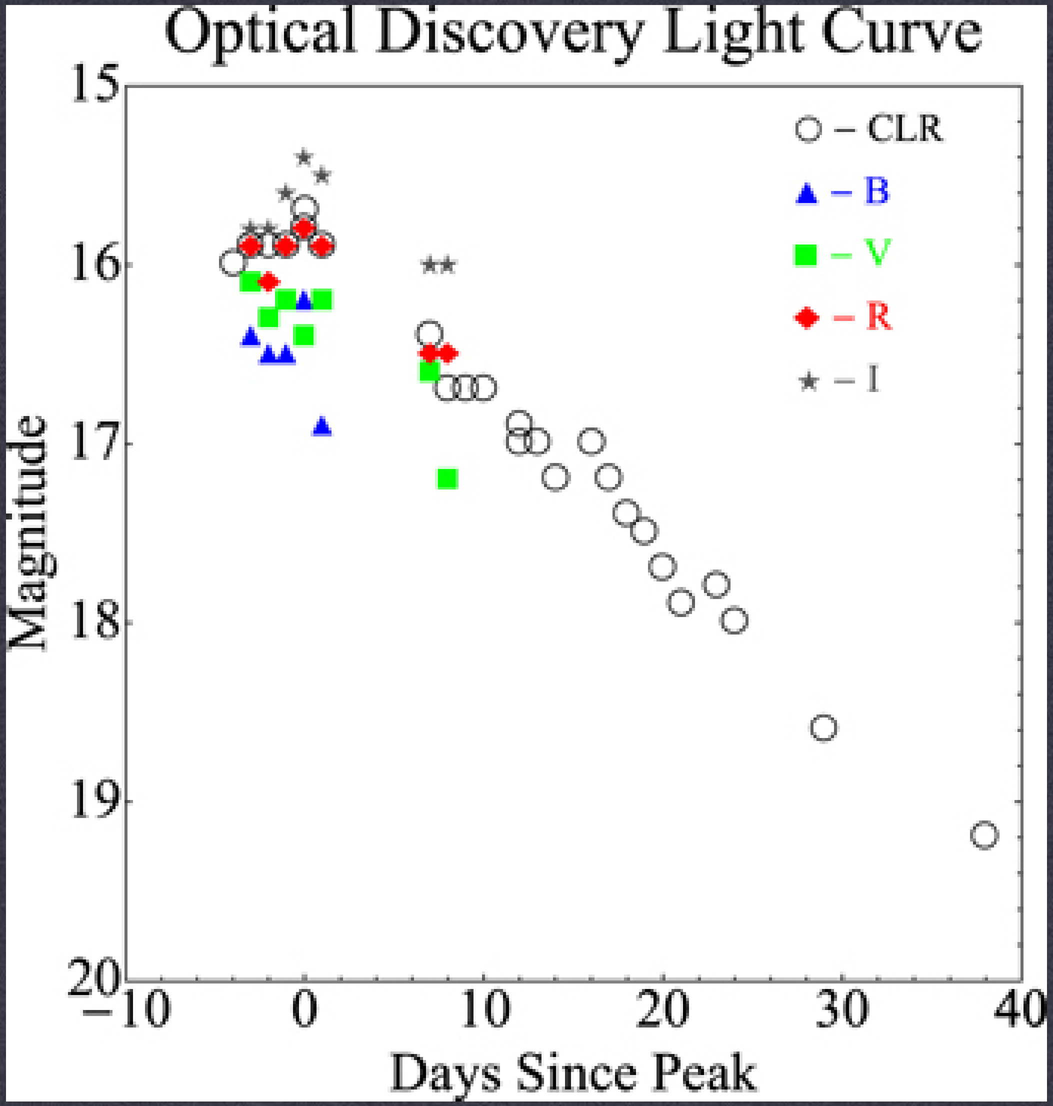
Dec 2016 in ULX state

Dec 2016 NuSTAR



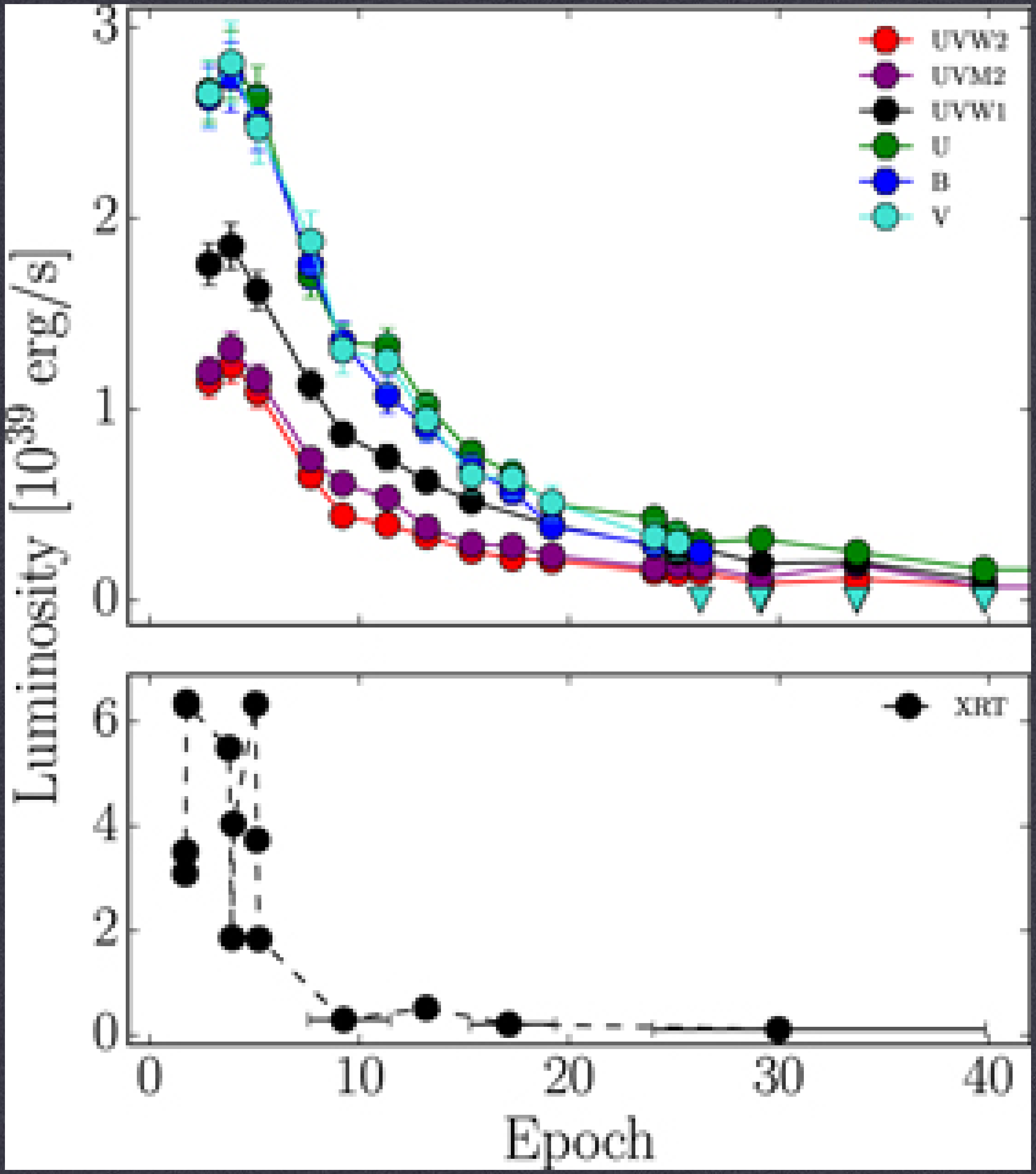
The supernova impostor SN 2010da

Bronberg Observatory



Lau et al. 2016

Swift UVOT/XRT in May 2010

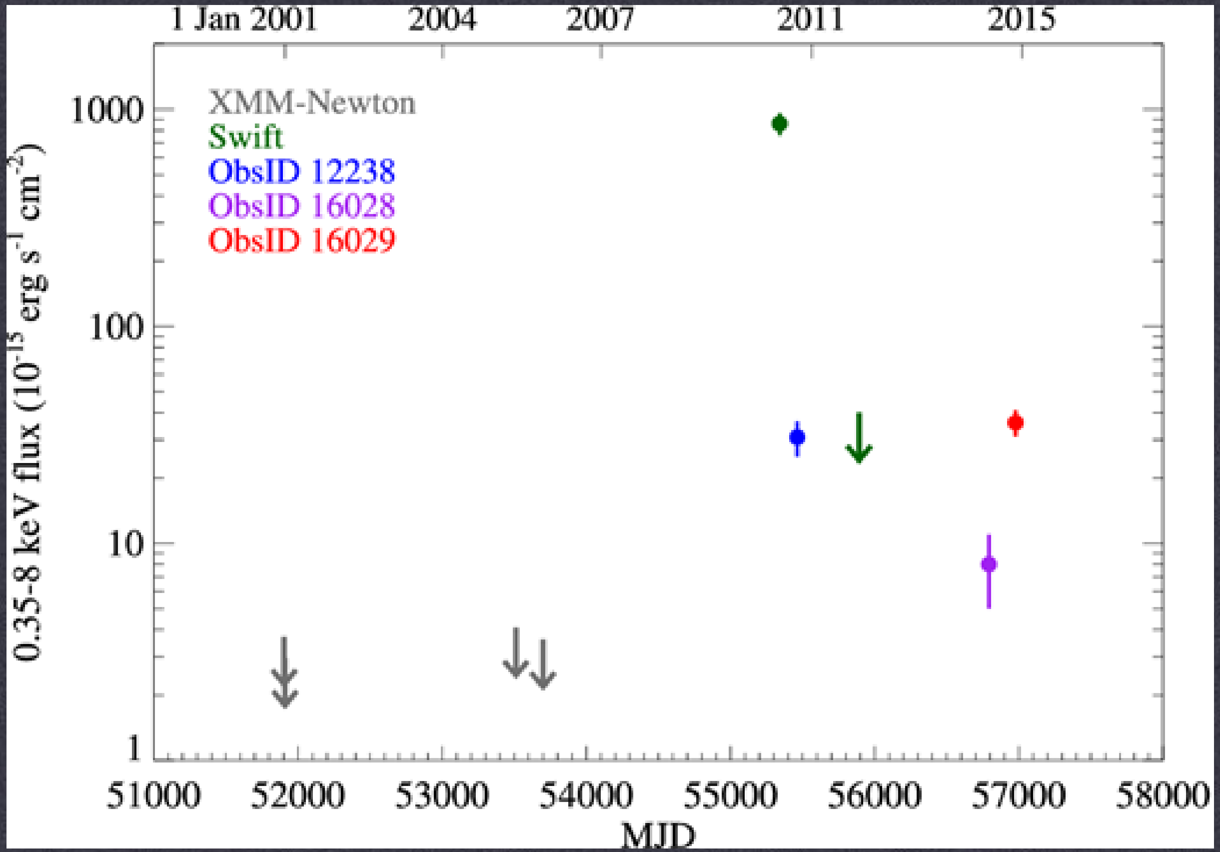


Villar et al. 2016

On 23 May 2010 a new bright source of ~16mag appeared at optical wavelengths, in UV and IR. Originally classified as a supernova.

The supernova impostor SN 2010da in X-rays

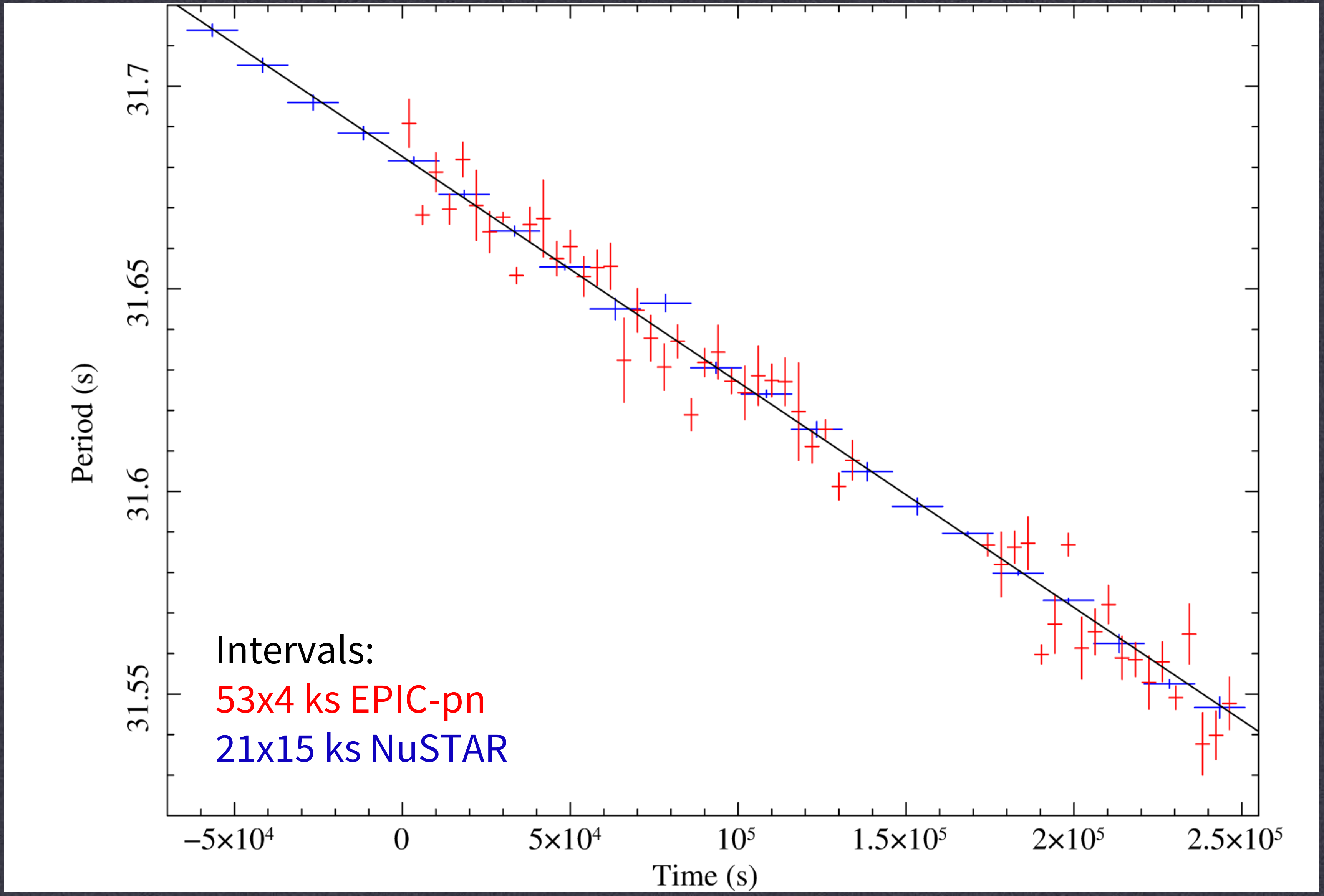
XMM-Newton
Swift
Chandra



Binder et al. 2016

- In 2010 detection by Swift XRT with $L_X \sim 6 \times 10^{38}$ erg/s, 4 months later by Chandra with $L_X \sim 2 \times 10^{37}$ erg/s.
- From the high X-ray luminosity associated to the large optical/IR flare, it was concluded the system was a high-mass X-ray binary in outburst (likely with a Be companion star)
- Chandra observations in May and November 2014, luminosity increased by a factor of ~10, from 4×10^{36} erg/s to 4×10^{37} erg/s .
- Caution: X-ray luminosities very model (absorption) dependent!

Pulsations in the Dec 2016 XMM/NuSTAR observations



P = 31.71s to 31.54s

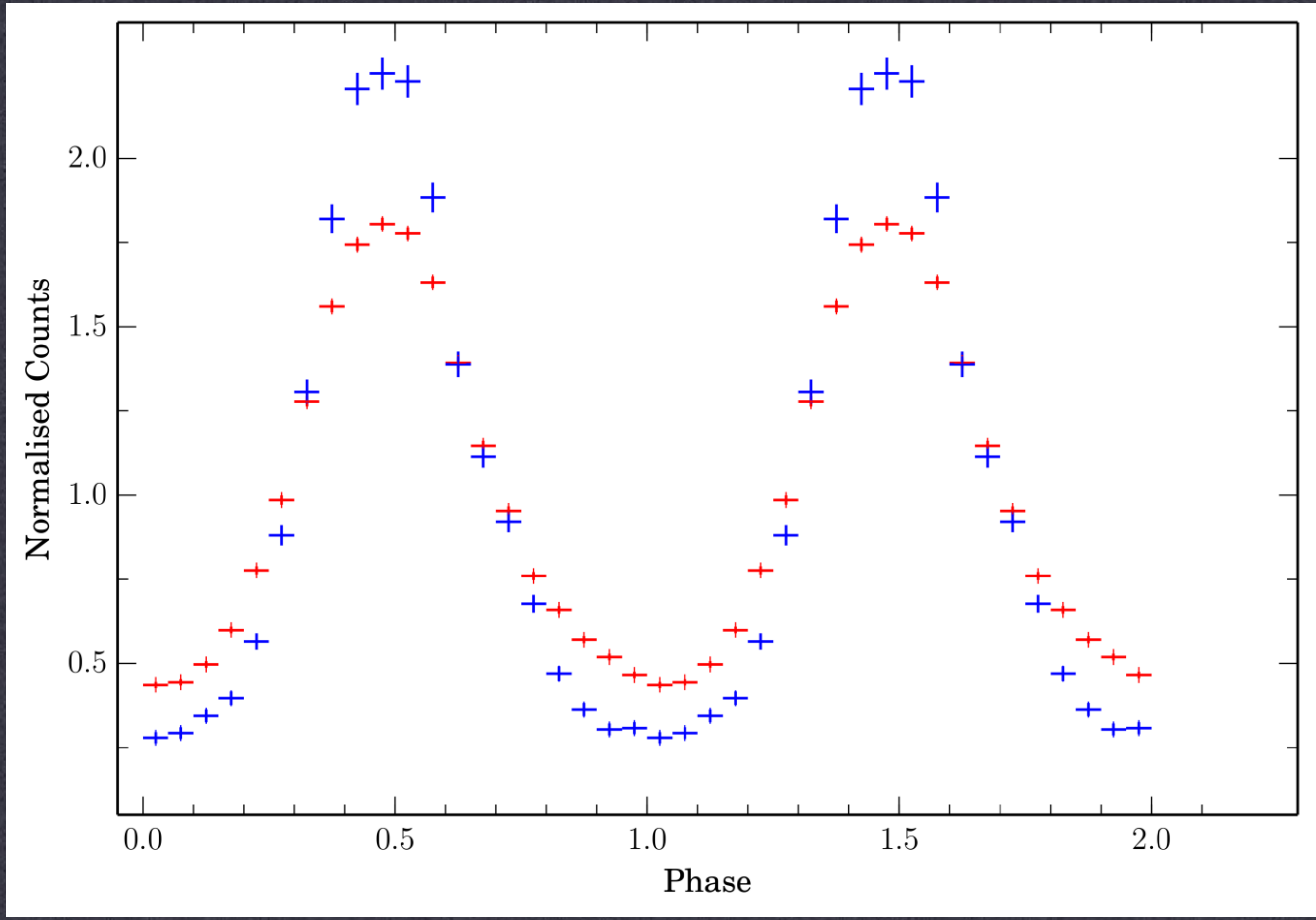
$\dot{P} = -5.56\text{x}10^{-7}$ s s^{-1} (over ~310 ks)

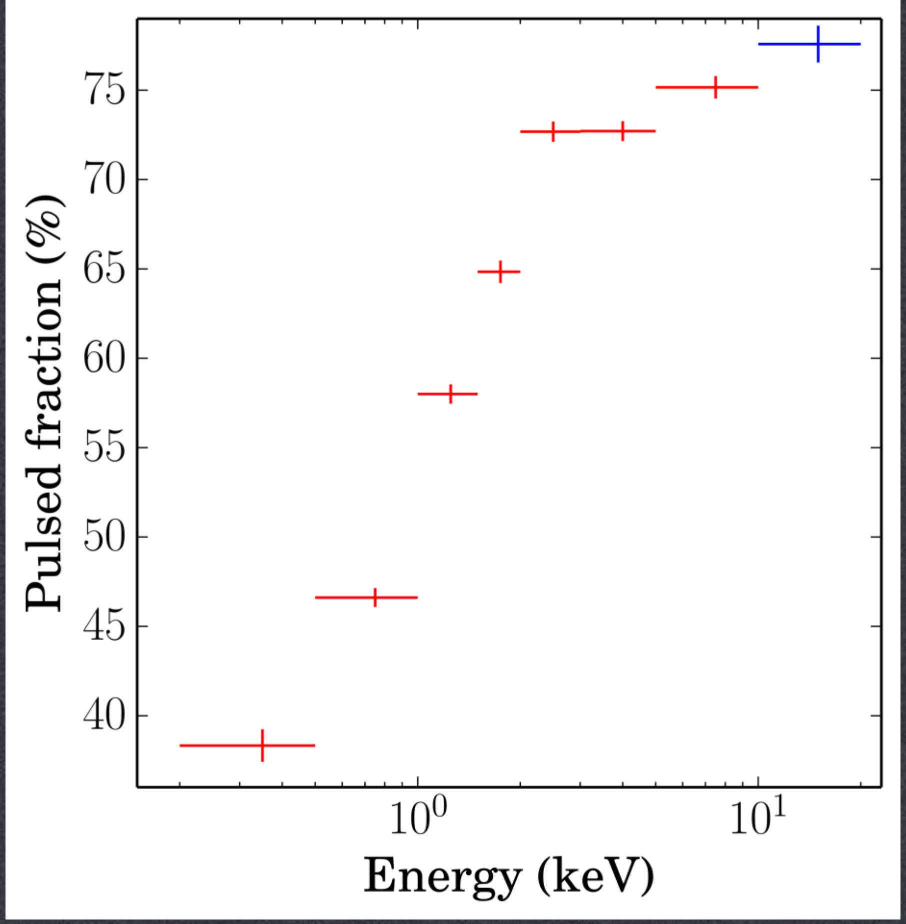
No significant orbital modulation (for P_{orb} between 1 and 3 days):

v sin(i) < 4.6x10^{-5}c; mass function f < 8x10^{-4} M_{sun}; i < few degrees

CHMV18

The pulse profile and its energy dependence





EPIC-pn (0.2-10 keV)
NuSTAR (3-20 keV)

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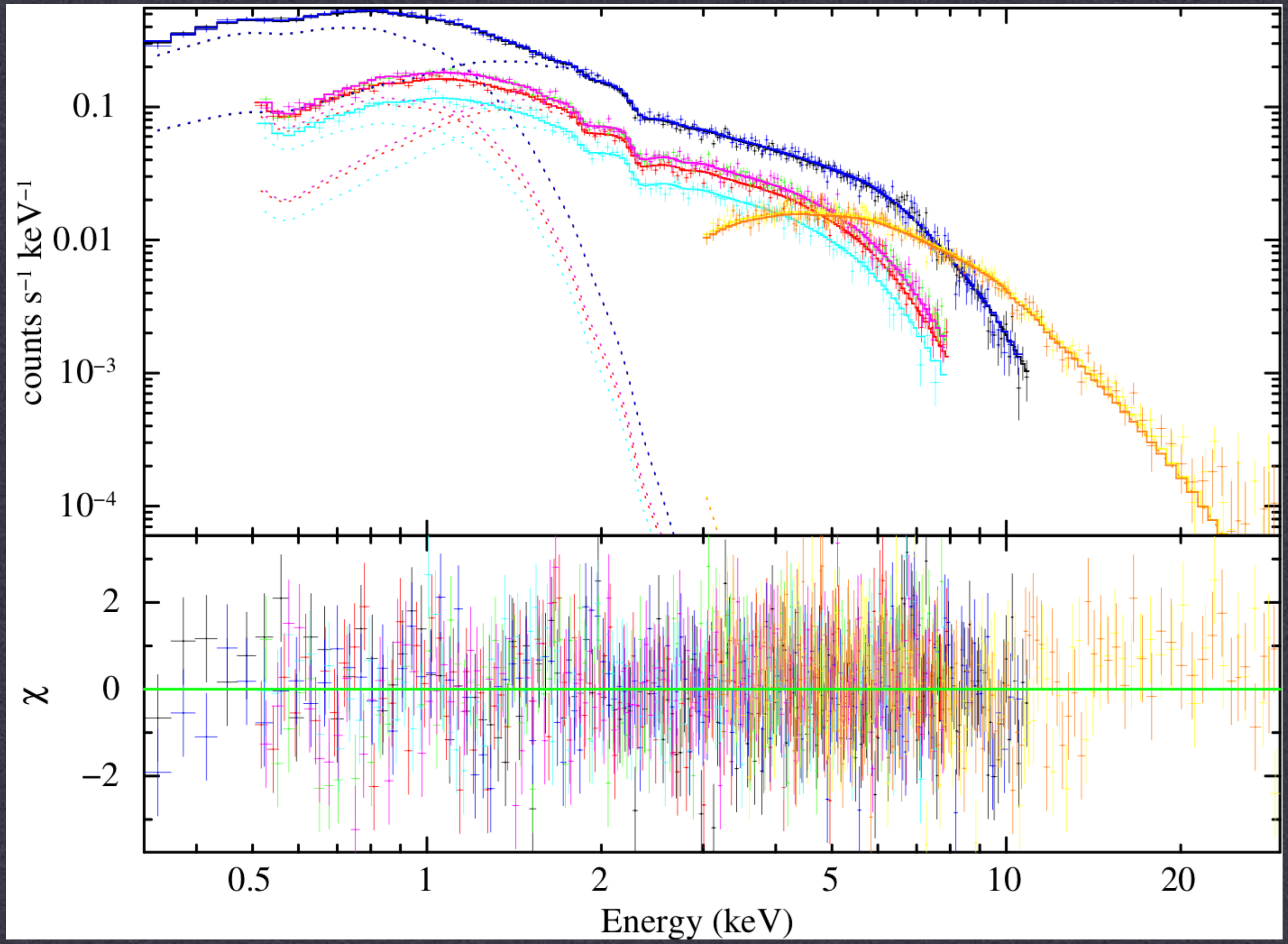
Spectral analysis of the Dec 2016 XMM/NuSTAR observations

Spectral model:
tbabs*pcfabs*(powerlaw*highecut+diskbb)



tbabs:
  Tuebingen-Boulder absorption model
pcfabs:
  partial covering absorption
  (0.75×10^{22} cm^{-2})
highcut:
  high-energy cutoff
  (Ecut 5.6 keV, Efold 7.0 keV)
diskbb:
  multi-temperature blackbody (0.18 keV)

Simultaneous fit to phase-averaged spectra:
$L_X = 4.7 \times 10^{39}$ erg/s
(0.3–30 keV, unabsorbed)

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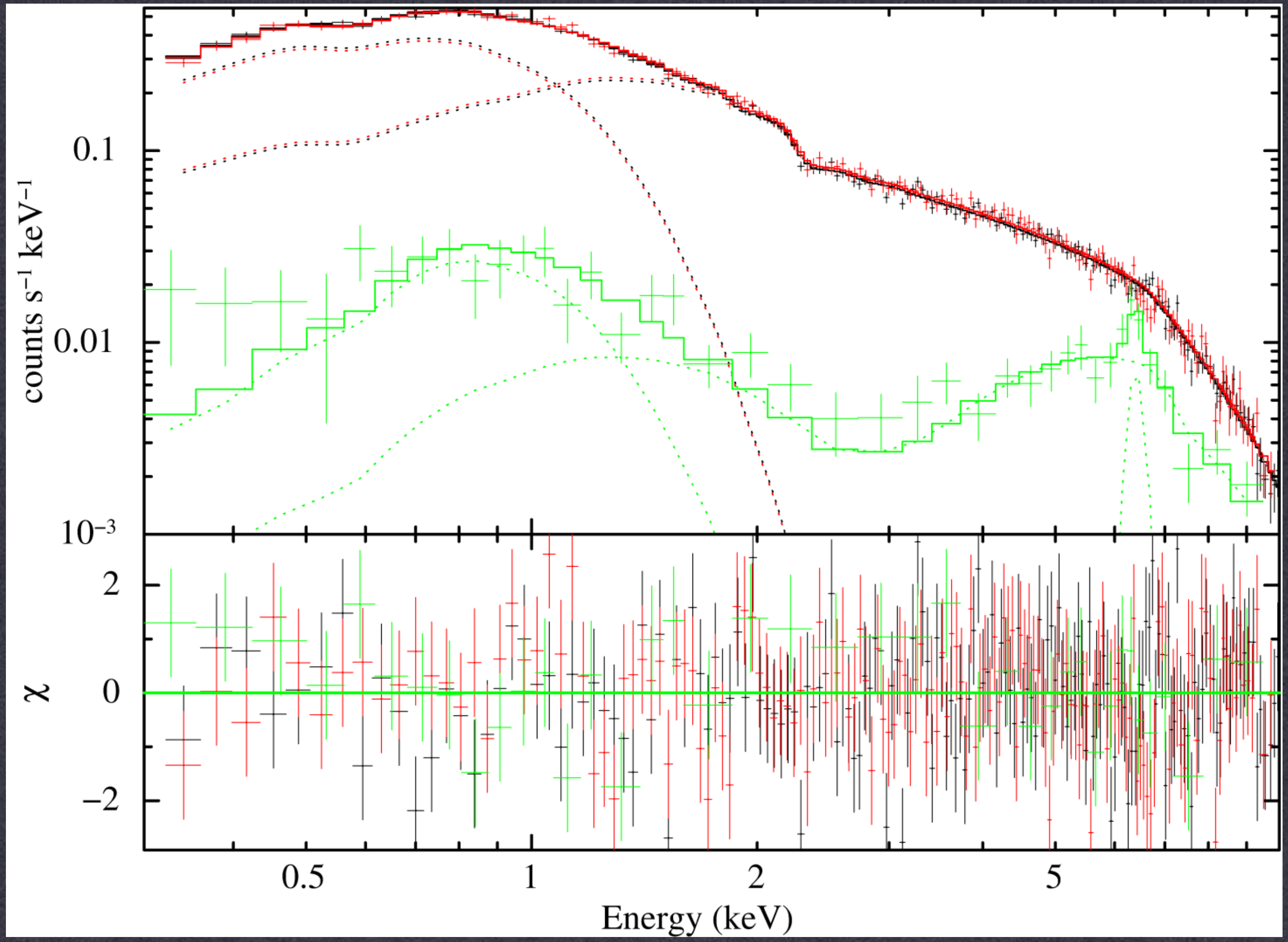
Spectral analysis of the 2010 & 2016 XMM observations

EPIC pn spectra from 2010 (green) & 2016 (red/black)



Same spectral model

Much higher absorption in 2010

(47.2 vs. 0.66) $\times 10^{22}$ cm^{-2}

In 2010 the observed flux was about 8 x lower, while the intrinsic luminosity was similar.

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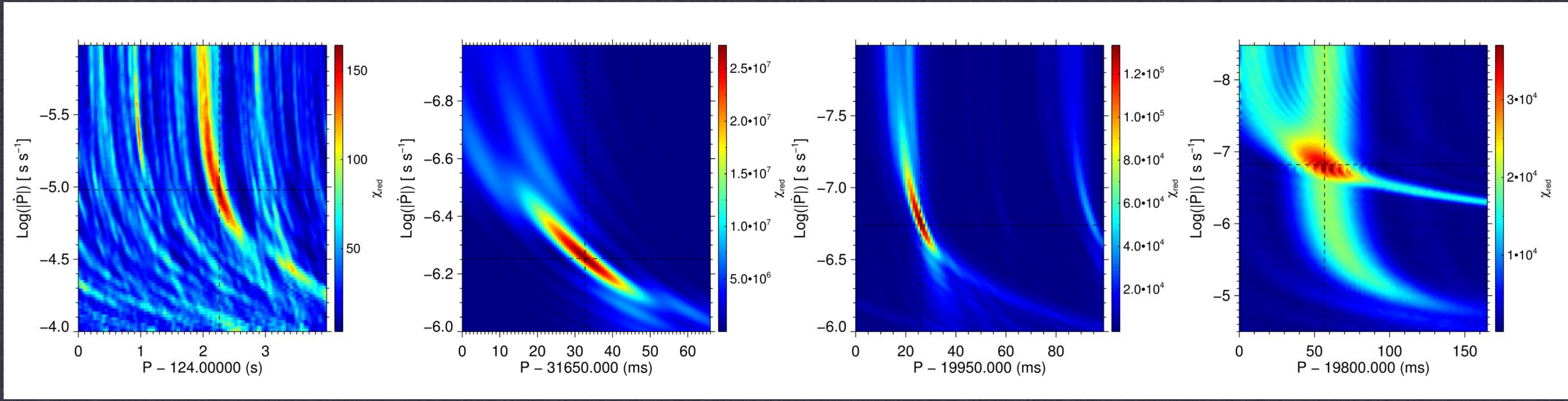
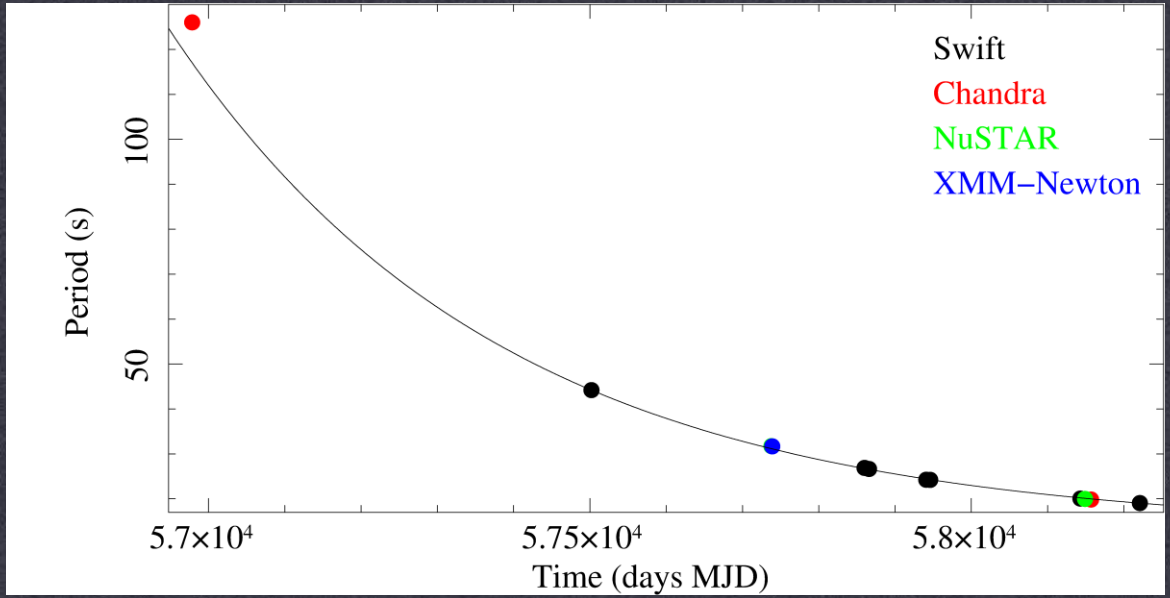
Long-term evolution of the pulse period



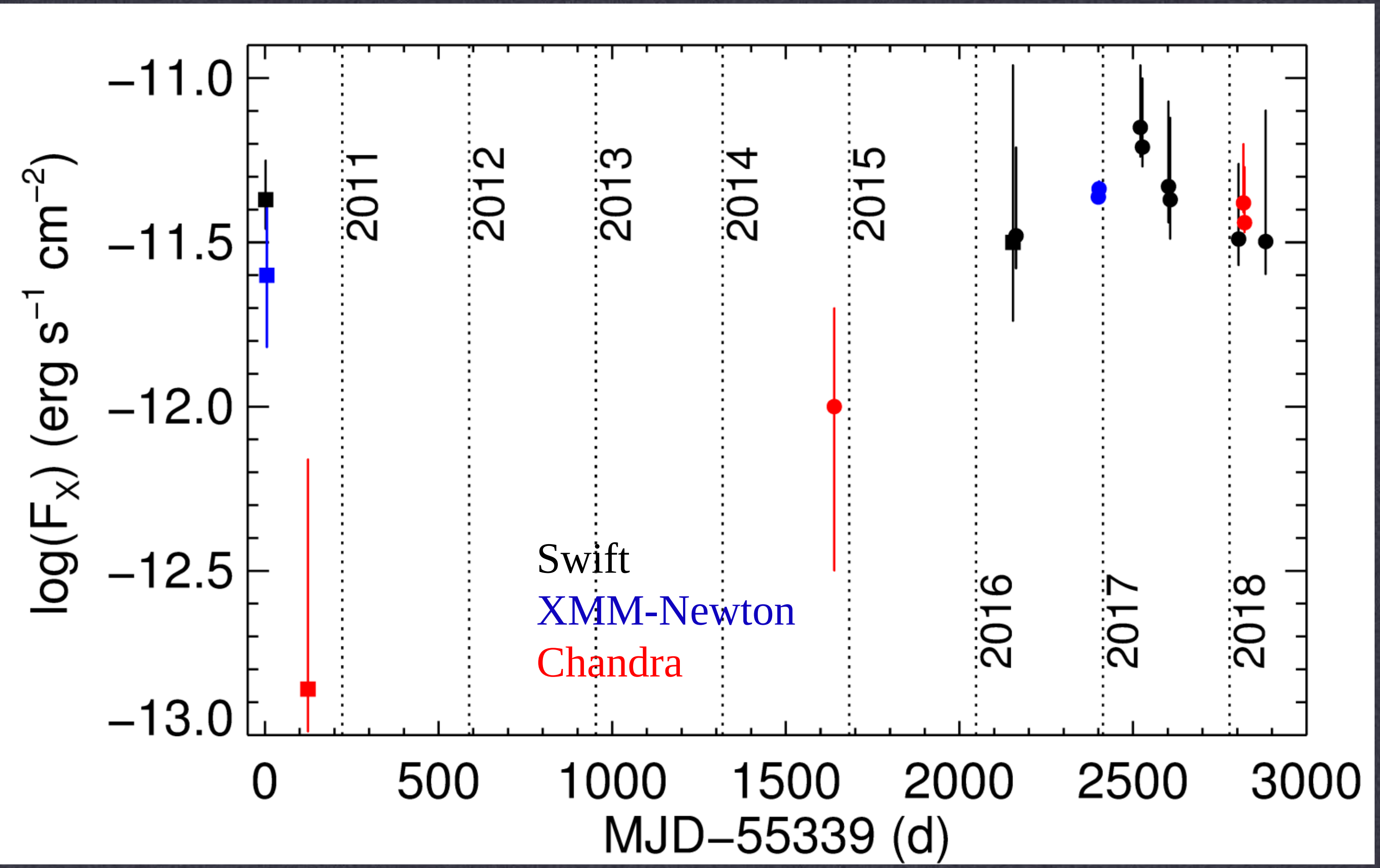
Chandra Nov 2014	XMM-Newton Dec 2016	NuSTAR Jan 31 2018	Chandra Feb 8/11 2018
126.3 ± 0.3 s	31.683 ± 0.001 s	19.976 ± 0.002 s	19.857 ± 0.002 s



Approaching equilibrium period
Depends on accretion rate

VHCM18

Long-term luminosity evolution



High absorption in early years causes most of the flux variations. Relatively small variations of intrinsic luminosity (accretion rate).

Absorption corrected flux (0.3-10 keV) of hard spectral component.

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NGC 300 ULX1 as test case for accretion torque theory

X-rays powered by release of gravitational potential energy

$L_x \approx GM\dot{M}/R_{NS}$

disk truncated at magnetospheric radius

$R_M \approx \xi R_{Alfven}$

accretion torque

$N_{acc} \approx \dot{M}\,\mathrm{sqrt}(GMR_M)$

$N_{tot} \approx n(\omega_{fast})\,N_{acc}$

$\omega_{fast} = (R_M/R_{co})^{3/2}$

$\longrightarrow 1$ transition to propeller regime

$n(\omega_{fast}) = [7/6-(4/3)\,\omega_{fast} + (1/9)\,\omega^2_{fast}\,]/(1-\,\omega_{fast})$

Wang (1995)

NGC 300 ULX1: ω_{fast} small ($n(\omega_{fast}) \rightarrow 7/6$)

other approximations (e.g. Parfrey+2016)

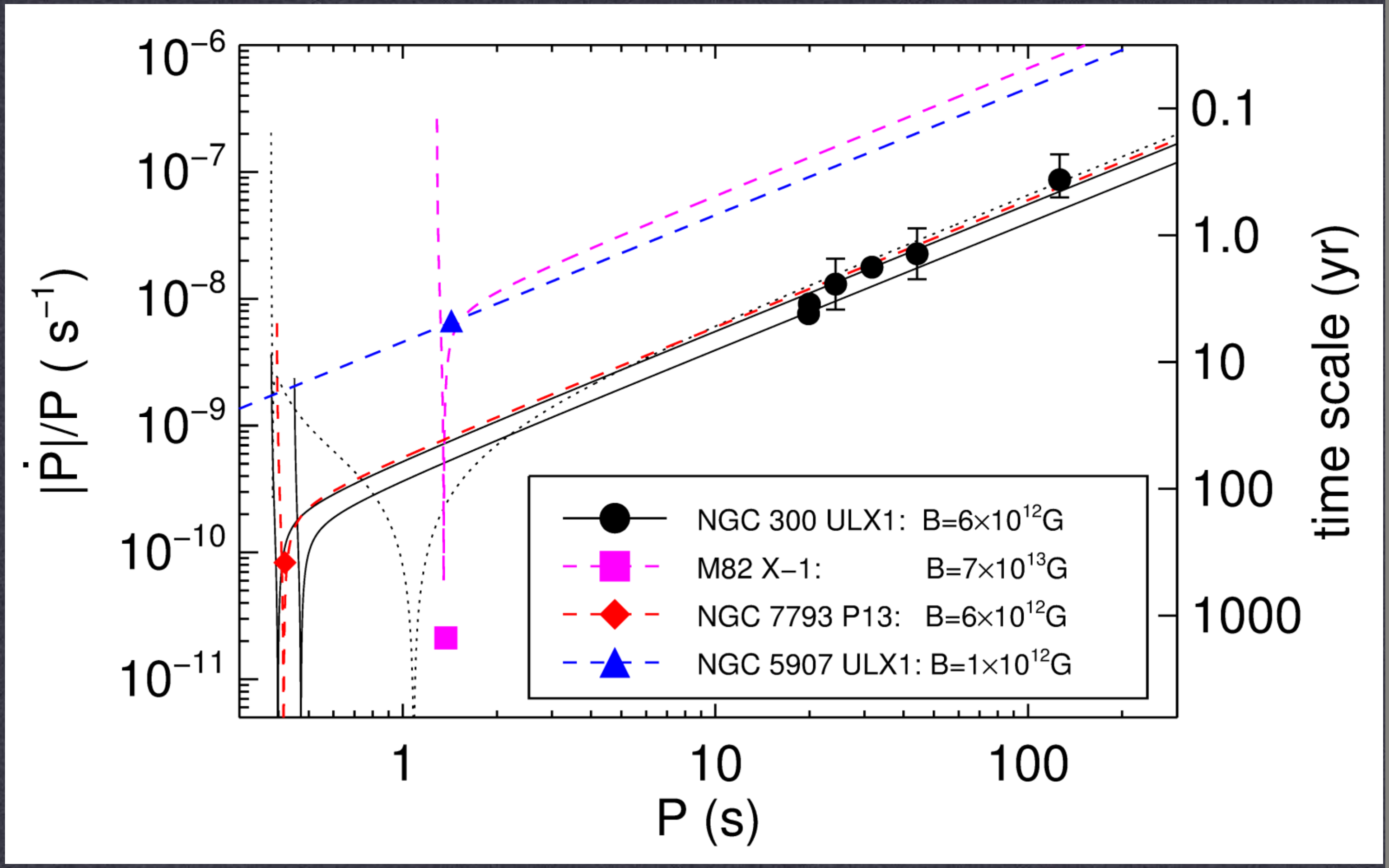
$-\dot{P}/P = P/(2\pi I_{NS})\,N_{tot}(B, P, L_x, M_{NS}, R_{NS})$

Observables P, $\dot{P}$ and L_x

+ Typical NS parameters

allows to estimate B

and to predict P-evolution (for given accretion rate)



Assumption of constant accretion rate

Solid black and coloured dashed lines: Wang (1995)

(NGC 300 ULX1: 2016 XMM and 2018 Chandra)

Black dotted line: Ghosh & Lamb (1979)

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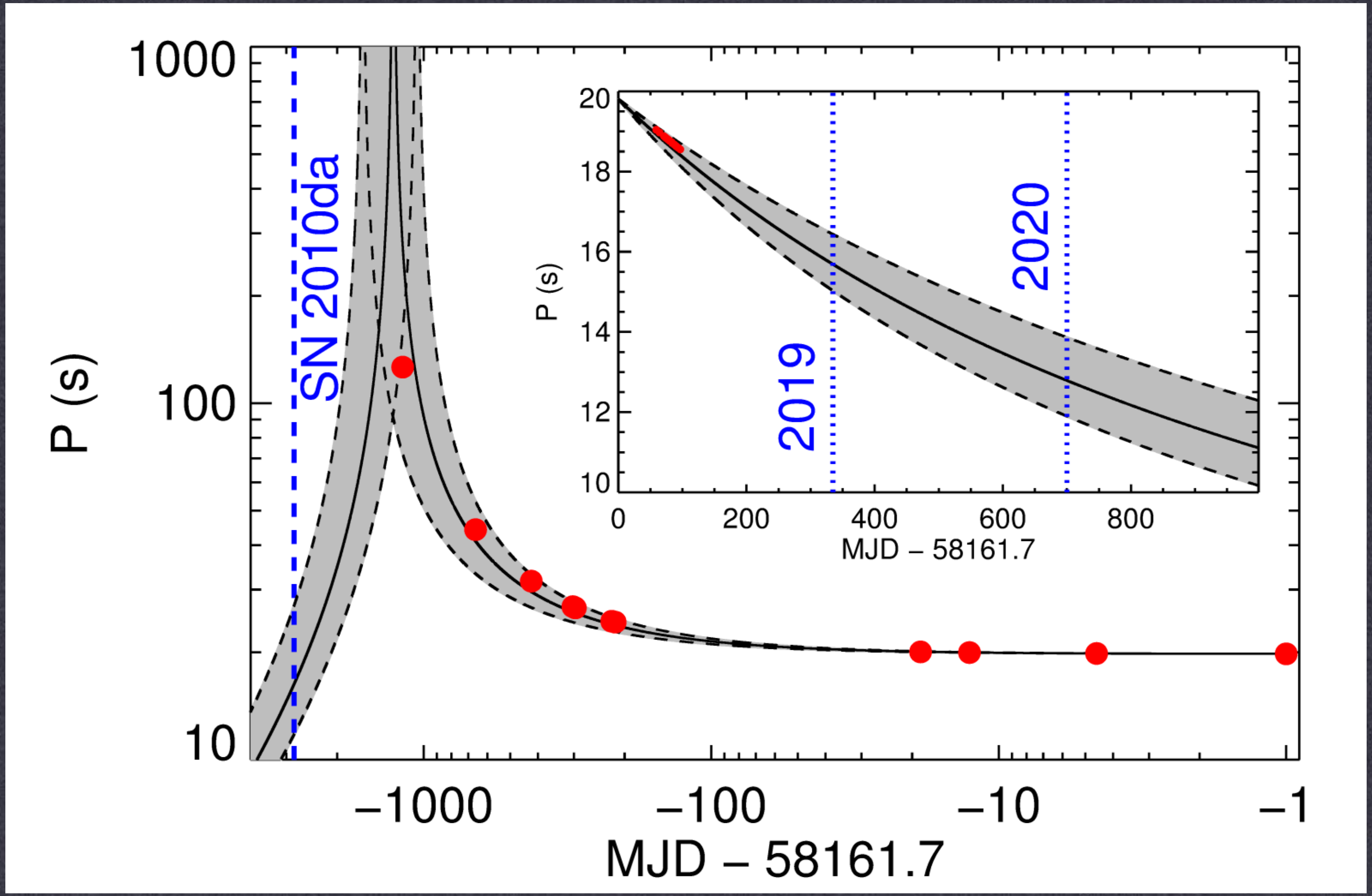
Past, present and future of NGC 300 ULX1



- NGC 300 ULX1 – a new ULXP with period far away from equilibrium
- Period evolution follows standard accretion theory
  $B_{equ} \approx 6x10^{12}$ G
  (developed for geometrically thin disk, sub-Eddington accretion)
- Accretion rate shows relatively little variations
  spin reversal of the NS before 2014?

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