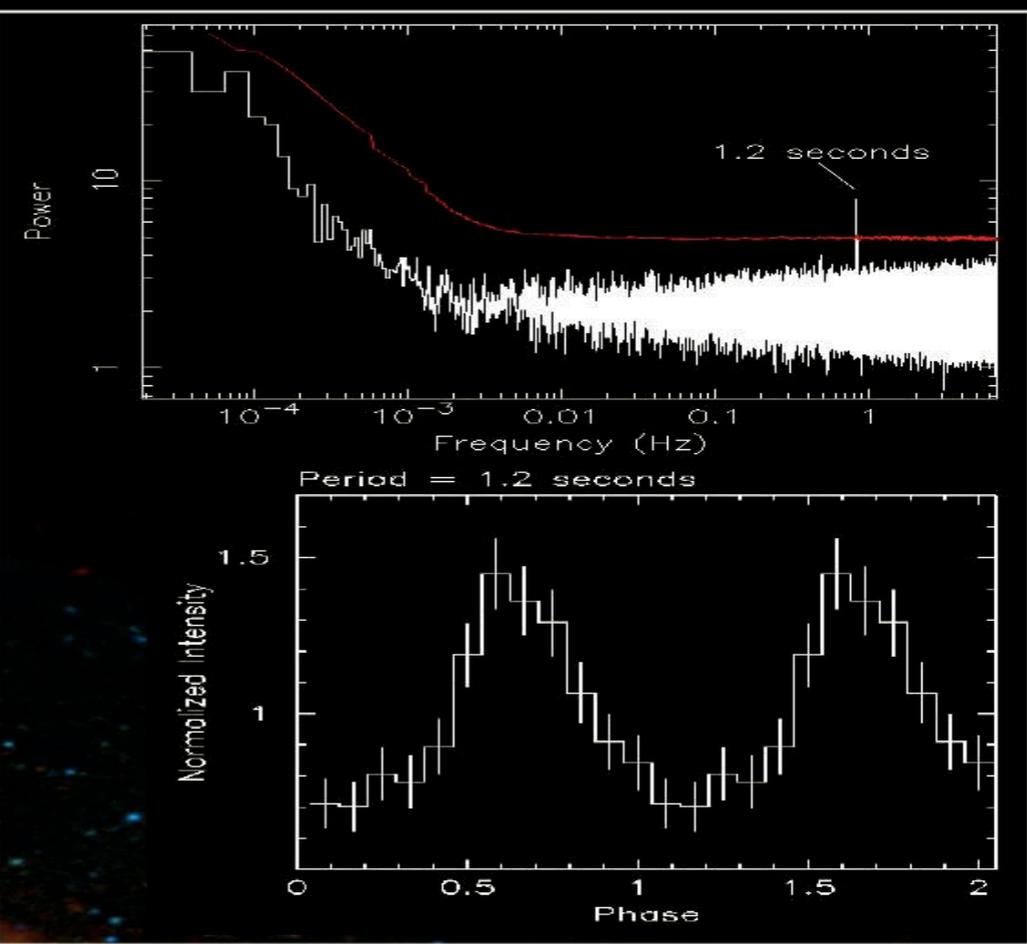




ANTON PANNEKOEK
INSTITUTE

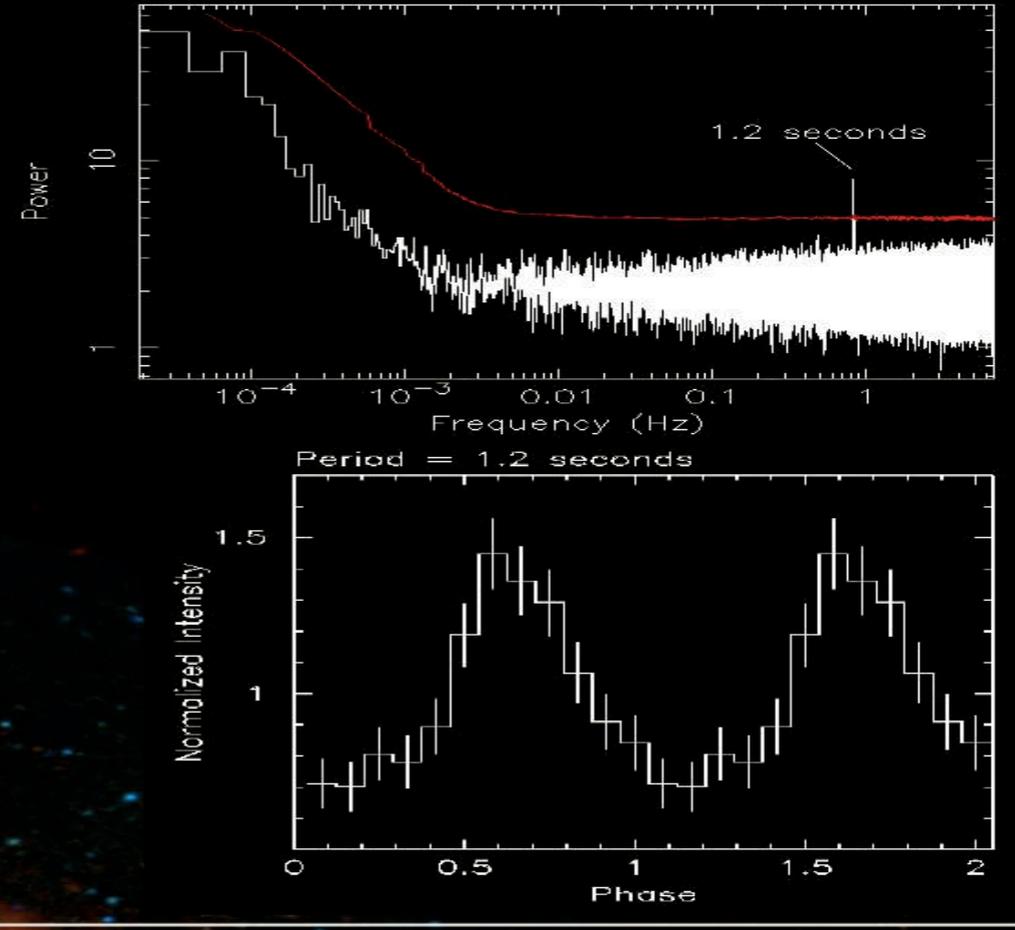


UNIVERSITEIT VAN AMSTERDAM



EXTRAS DISCOVERY OF AN 1.2-S PULSAR IN M₃₁

PAOLO ESPOSITO



+ G. L. ISRAEL, A. BELFIORE, G. NOVARA, L. SIDOLI,
G. A. RODRÍGUEZ, A. DE LUCA, A. TIENGO AND SEVERAL
OTHER PEOPLE OF THE EXTRAS COLLABORATION



CinemaScope

Coherence **IN** Epic detectors:

Mega **A**nalysis and **S**earch for **CO**herent **PE**riodicities



<http://www.extras-fp7.eu/>

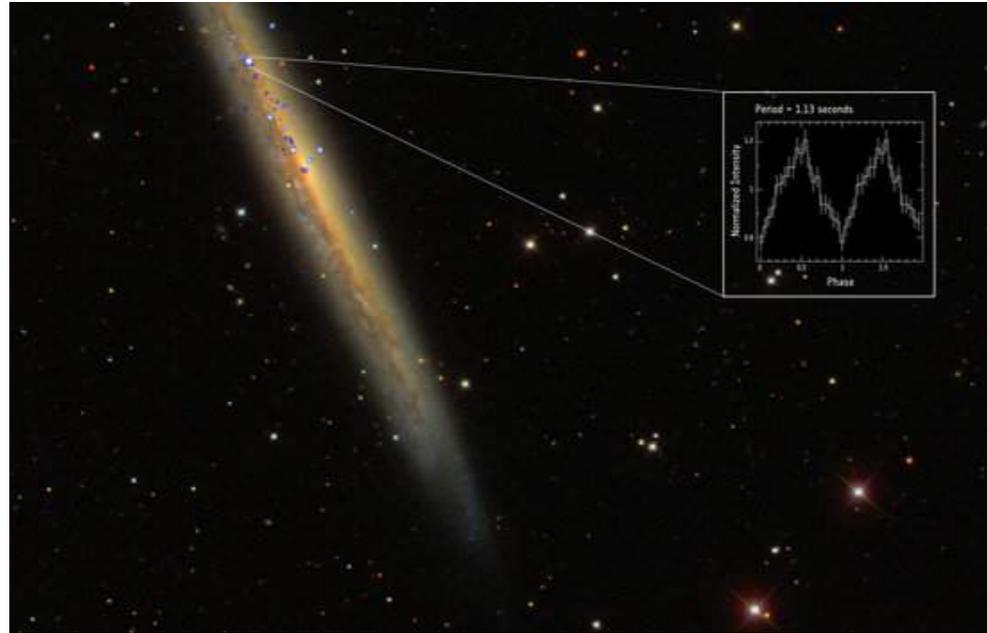
~15 years of public data
>10⁴ datasets, >6 × 10⁵ sources
~10⁶ timing series searched

>3 × 10⁶ FFTs carried out
~100,000 peaks
>50 new X-ray pulsators

SATS, CATS: Swift / Chandra Automatic Timing Surveys
Israel, Esposito, Rodríguez, Sidoli, 2016, MNRAS 462, 4371

Online catalog (>40 new X-ray pulsators):
<http://www.oa-roma.inaf.it/HEAG/catsatbar/>

First XMM / EXTraS published results



NGC 5907 X-1: record-breaking pulsar

THE BRIGHTEST, FURTHEST PULSAR IN THE UNIVERSE

21 February 2017

ESA's XMM-Newton has found a pulsar – the spinning remains of a once-massive star – that is a thousand times brighter than previously thought possible.

2 new ULX/PSRs:
NGC 7793 P13 (0.42 s) and
NGC 5907 ULX (1.1 s), the
brightest PSR known,
 $L > 10^{41} \text{ erg s}^{-1}$

Israel+17, Science 355, 817

Israel+17, MNRAS 466, L48

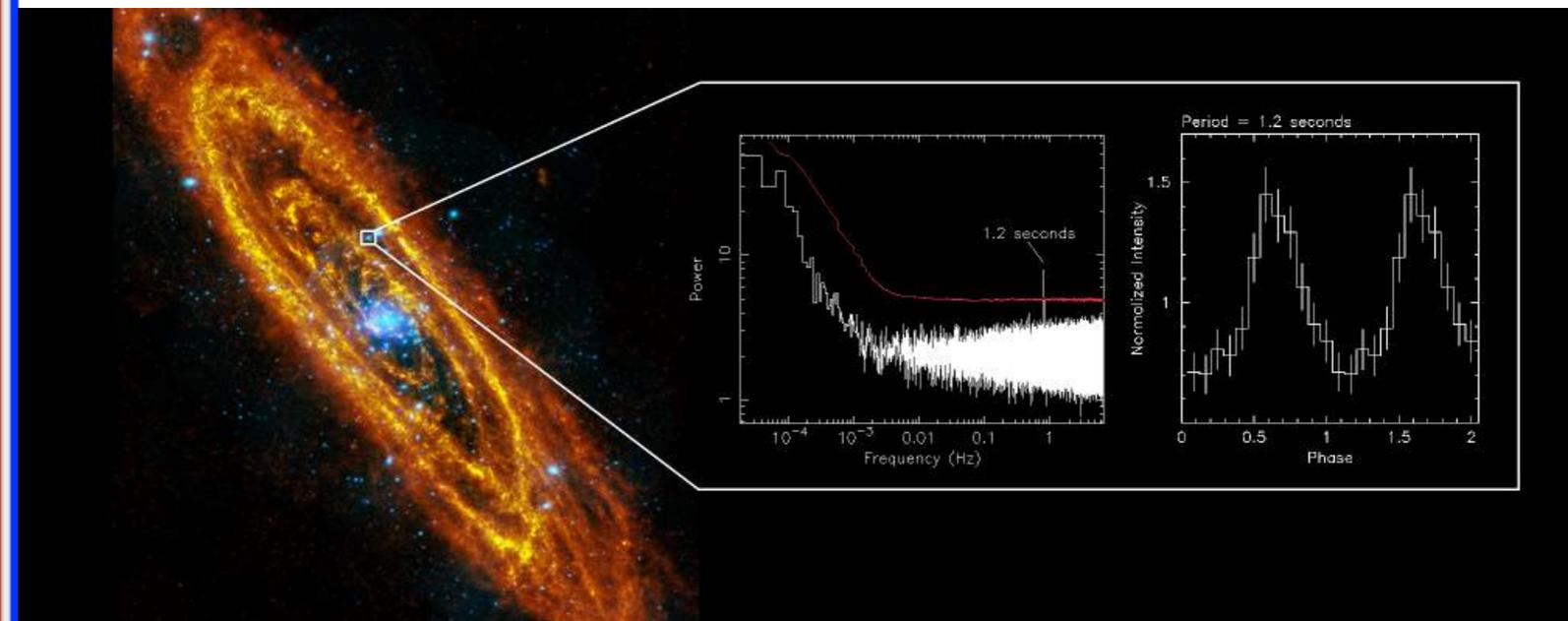
News

30-May-2017 11:44:09

Found: Andromeda's first spinning neutron star

31 March 2016

Decades of searching in the Milky Way's nearby 'twin' galaxy Andromeda have finally paid off, with the discovery of an elusive breed of stellar corpse, a neutron star, by ESA's XMM-Newton space telescope.



The 1.2-s 3XMM J0043

Esposito+16, MNRAS 457, L5

Andromeda / M31 / NGC 224



- Visible to the naked eye
- millennial debate on its nature (settled in 1925 by E. Hubble)
- $D \sim 780$ kpc
- Barred spiral, $i \sim 78^\circ$
- $M \sim 1.5 \times 10^{12} M_\odot$ ($\sim 2 \times \text{MW}$)
- $SFR \sim 0.25 M_\odot \text{ yr}^{-1}$ (SN 1885A)

Sisyphus

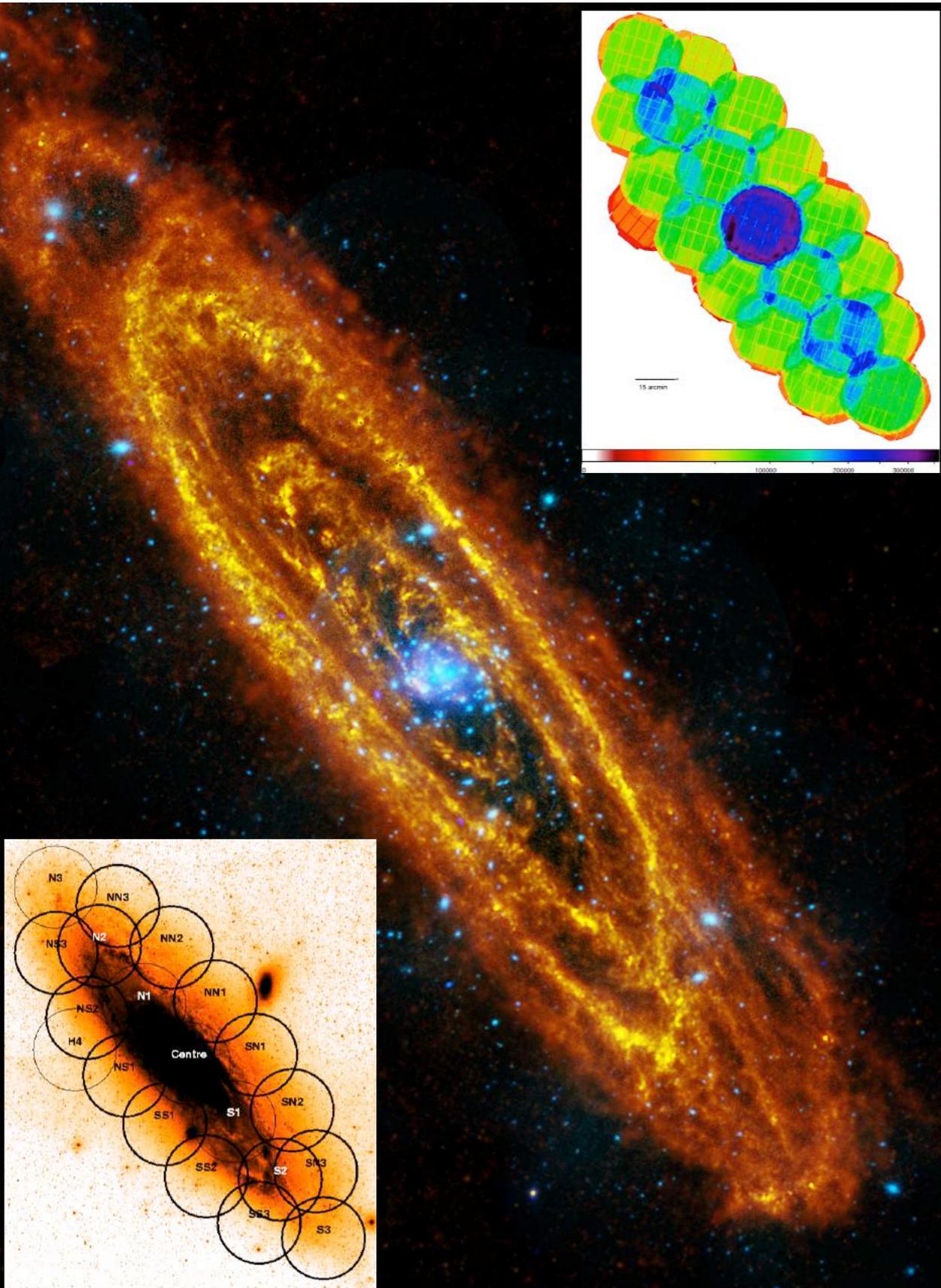
A. Carracci

T. Łempicka



>2- μ s XMM + Herschel image

J. Fritz, U. Gent, W. Pietsch – Stiele et al. 2011

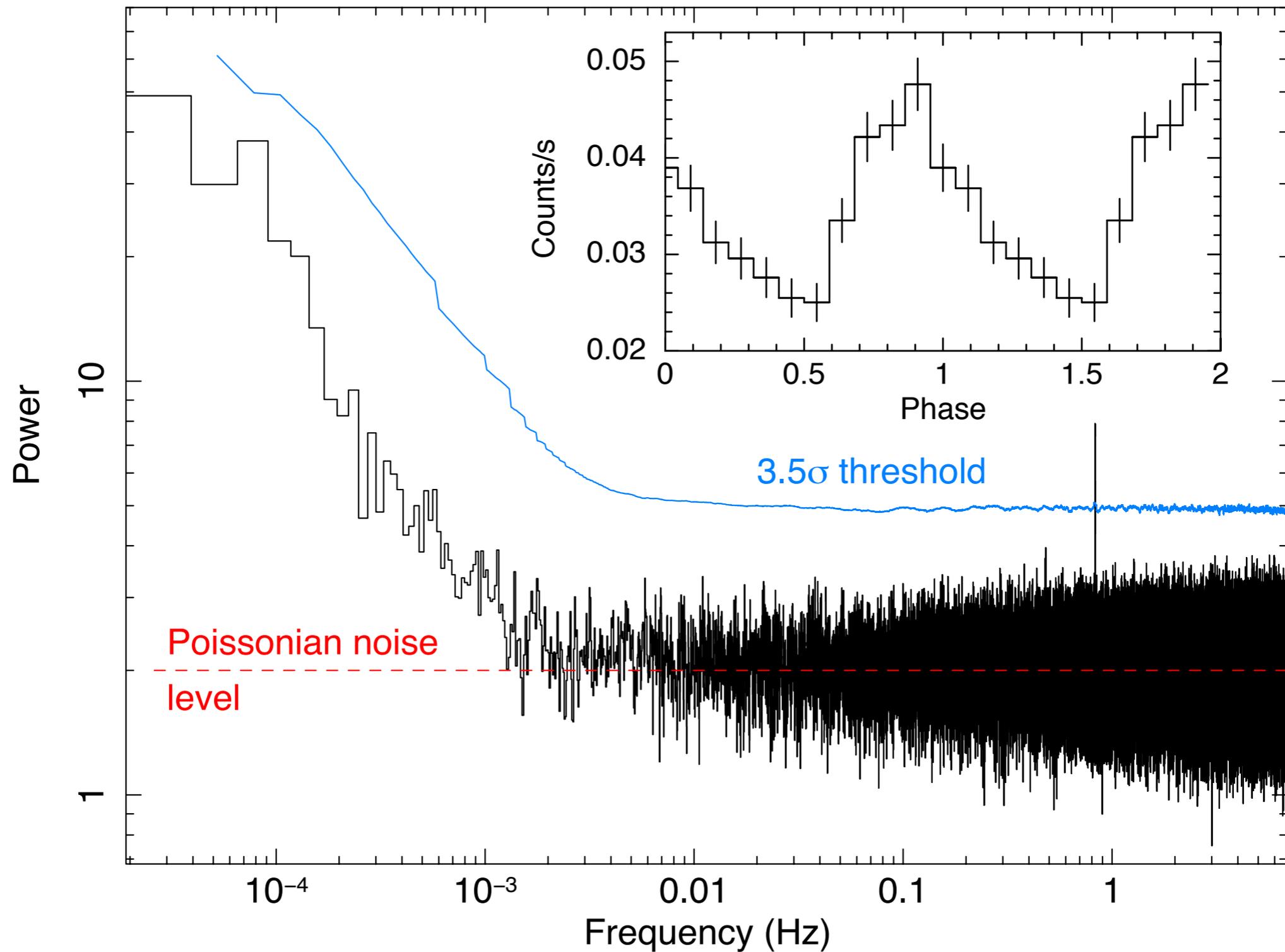


XMM and M31

Stiele et al. 2011

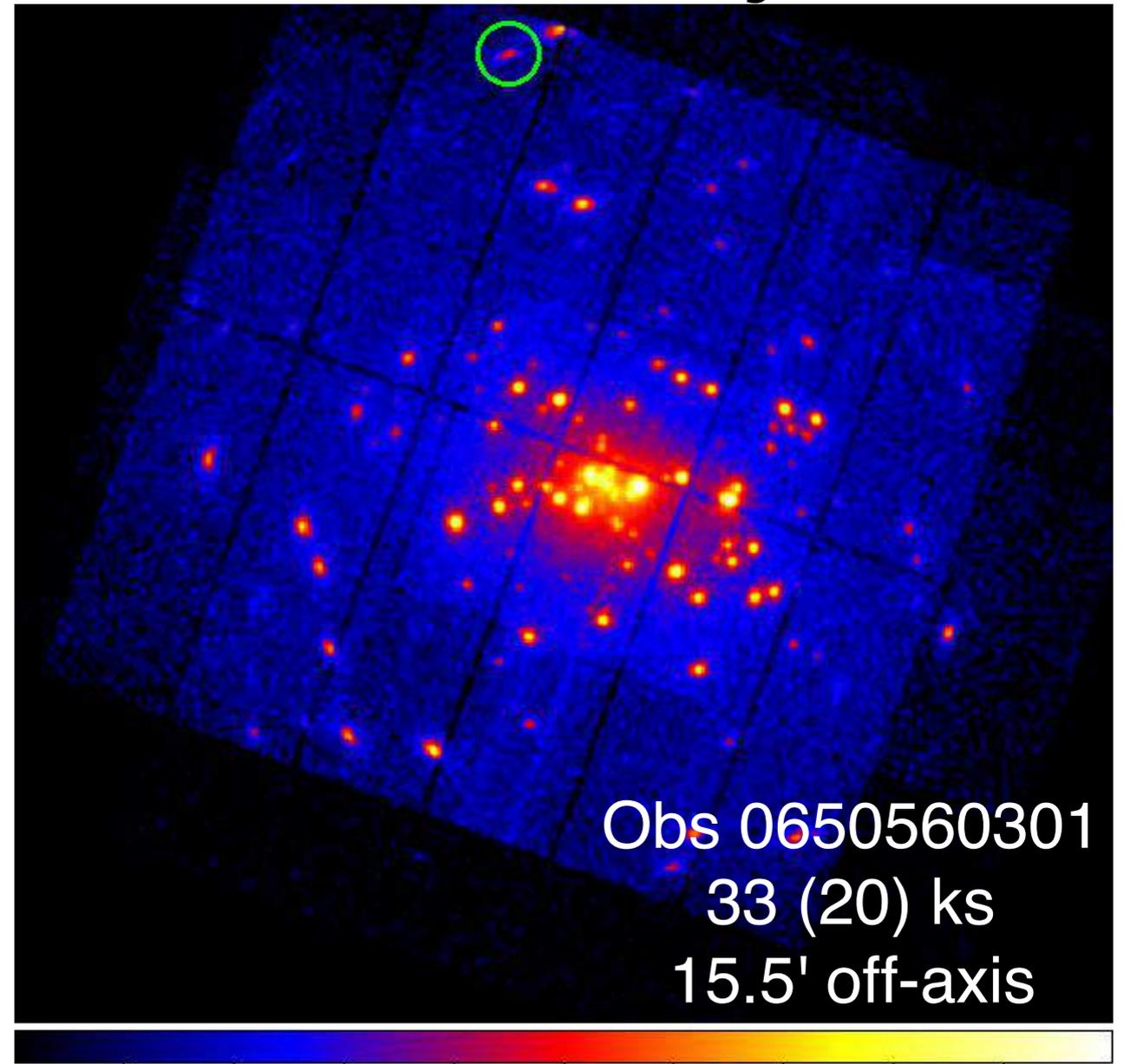
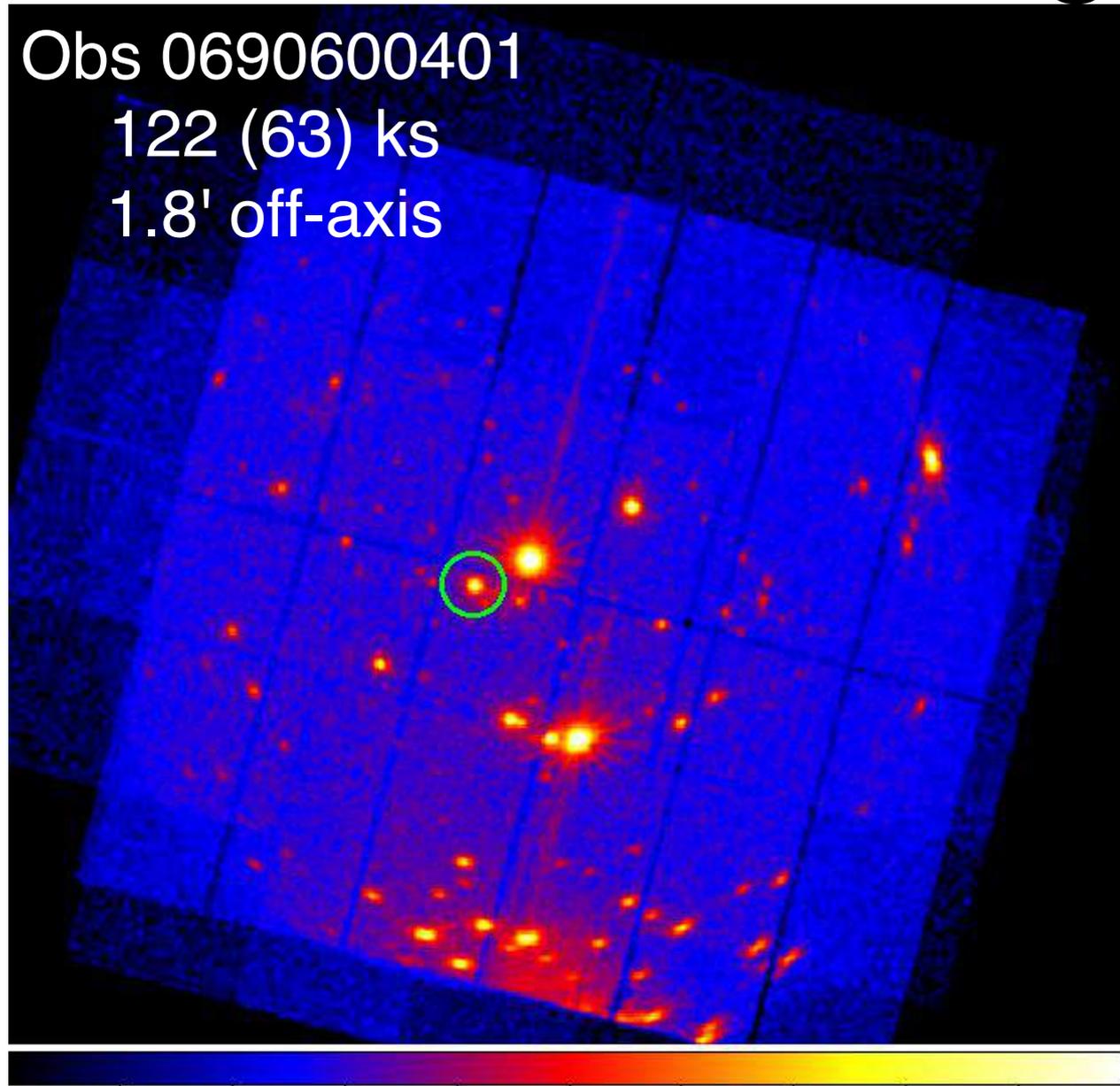
- M31 **completely imaged** down to $\sim 10^{35}$ erg s $^{-1}$ (0.2–4.5 keV)
- **1897 X-ray sources**, many bright XRBs and candidates (spectrum, MWL, variability)
- **36 LMXBs + 17** candidates possibly associated to globular clusters or candidates
- Periodic signals: **2 SSSs (217 and 865 s)**; candidate signals at 8.3 and **197 s**, never confirmed
- *'Not a single secure NS spin in M31 has been confirmed.'*

1.2-s modulation: a spinning NS!

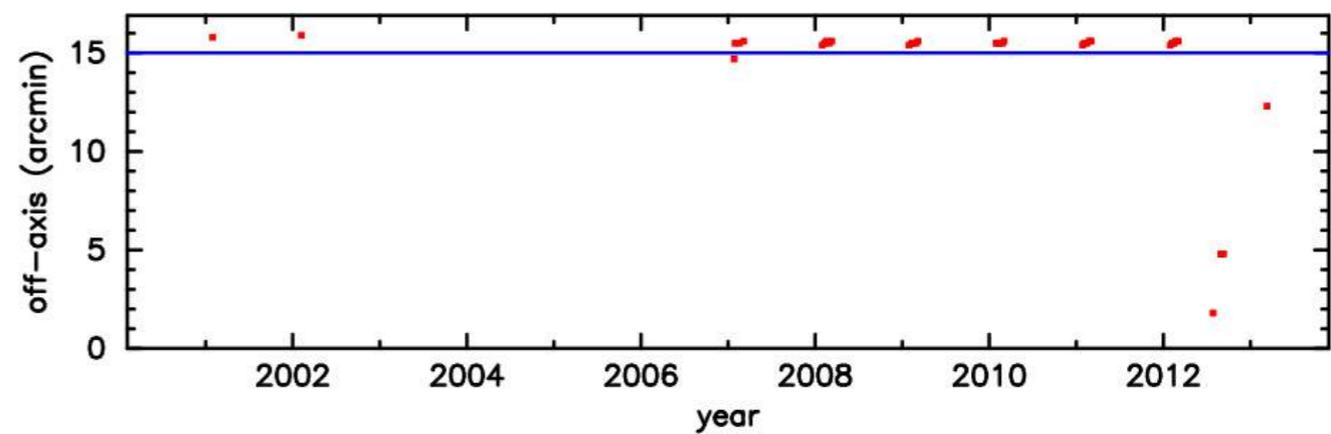
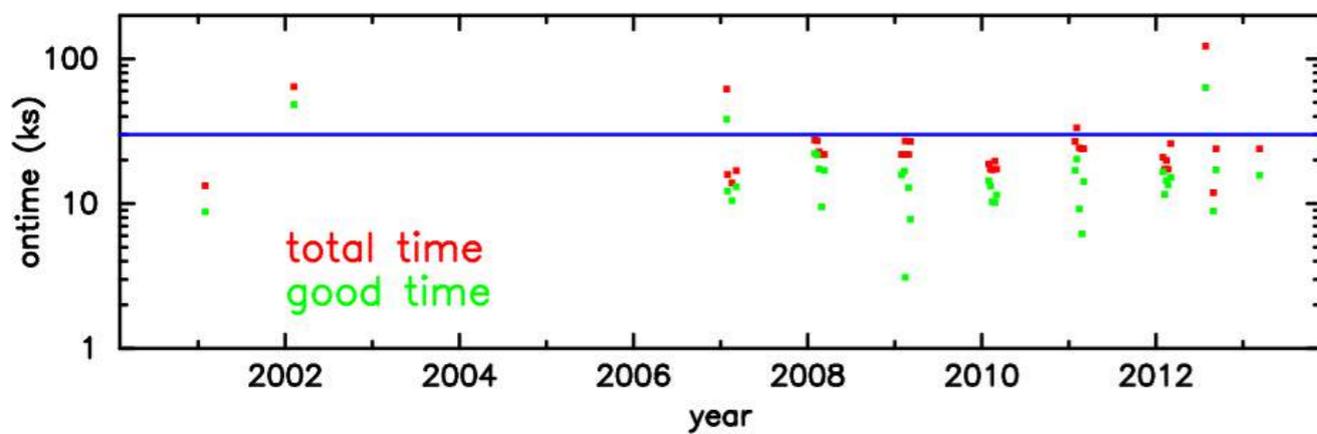


First discovered at 6.5σ c.l. in a 2011 30-ks observation
> 12σ combining more data sets

3X J0043 was imaged 35 times by XMM

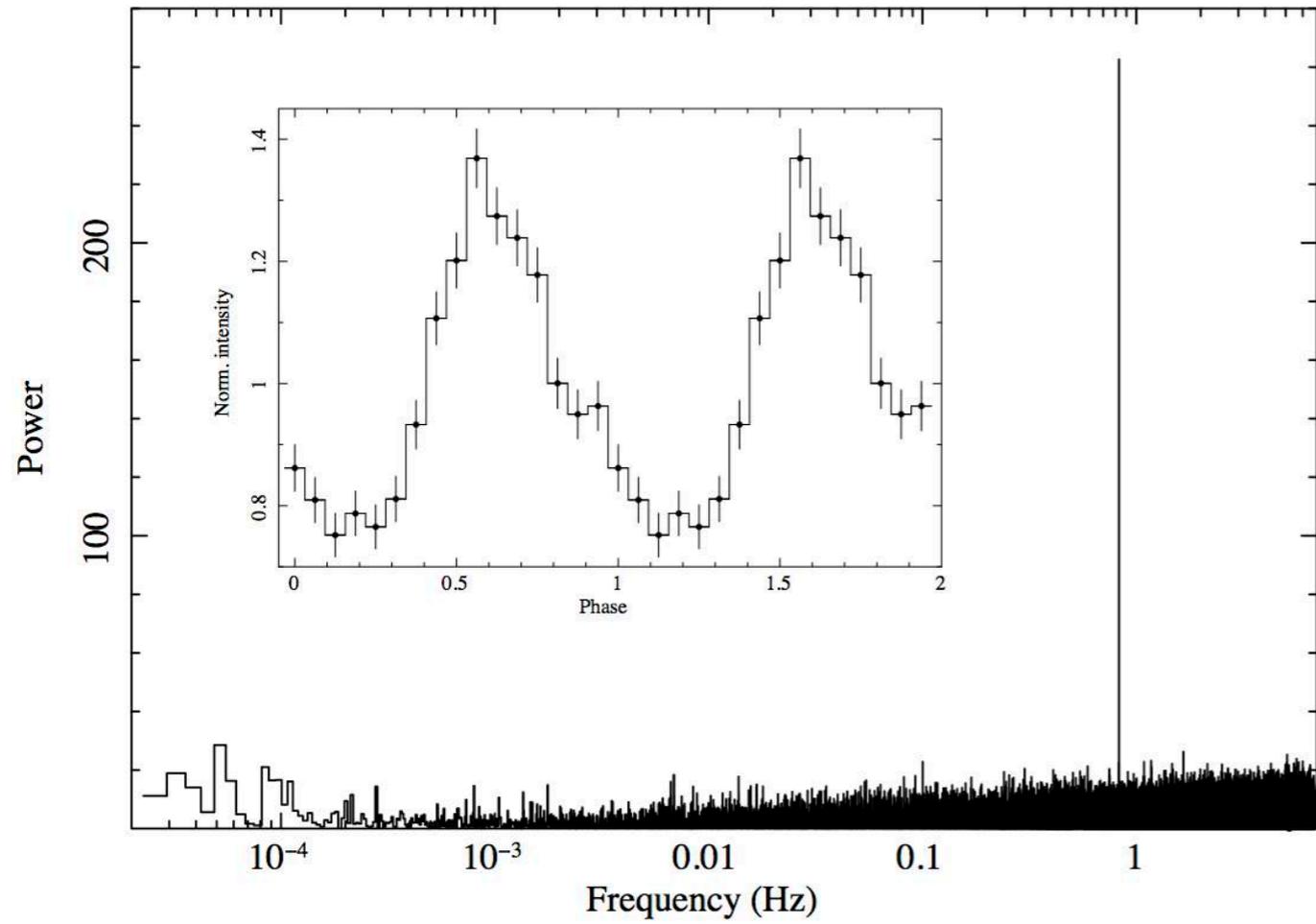
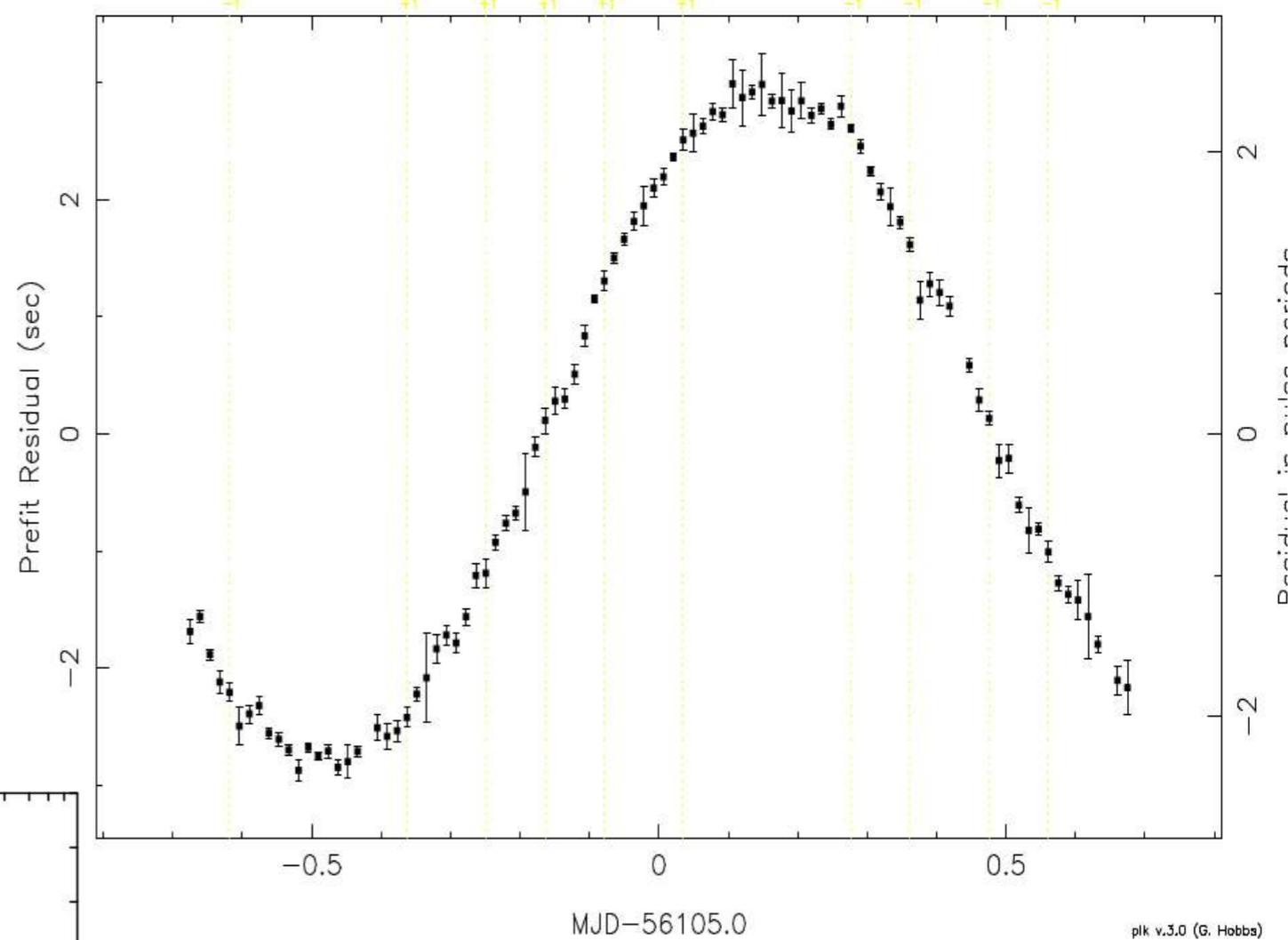
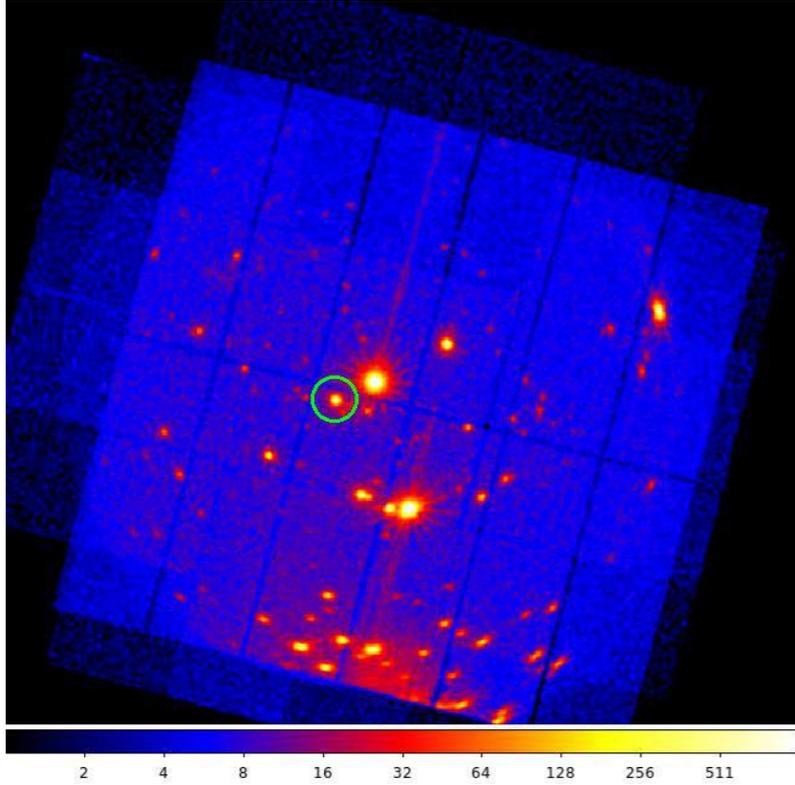


Mainly **short** (<30 ks) **off-axis** (>15') observations



In the longest observation

Obs. 0690600401
122 (63) ks
1.8' off-axis

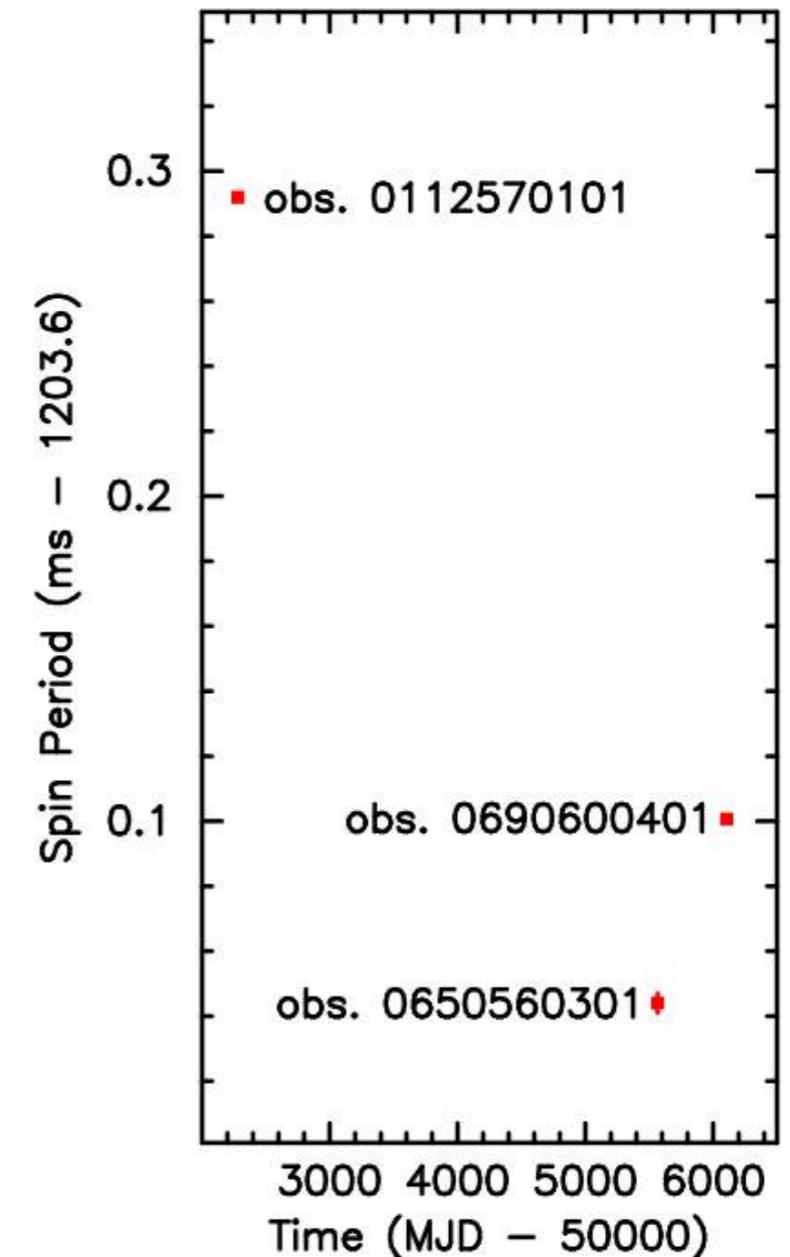


Doppler shifts from an
1.3-d orbit

But little or no flux modulation
($< 10\%$) at the orbital period

Evidence of spin-up and -down

Orbital period (d)	1.2739783(8)
T_0 asc. node (MJD)	56104.791(1)
Proj. semiaxis (lt-s)	2.884(17)
Eccentricity	<0.037 (3σ)
Companion mass (M_{\odot})	>0.36



Ephemeris locks the orbit and fits P (no dP/dt)
(see also Zolotukhin et al. 2017)

If the NS is close to the **equilibrium period** ($R_{\text{mag}} = R_{\text{cor}}$),

$$B \approx 1.3 \times 10^{12} \text{ G}$$

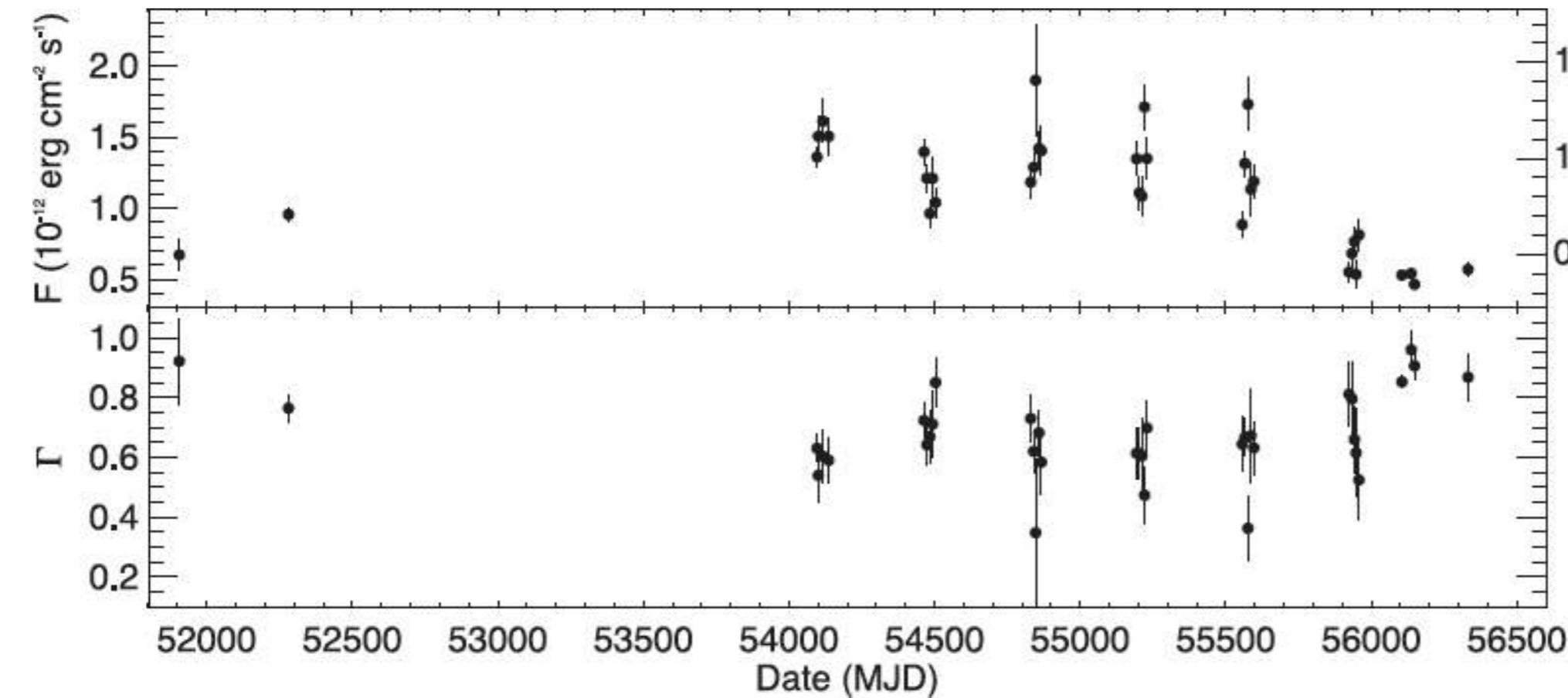
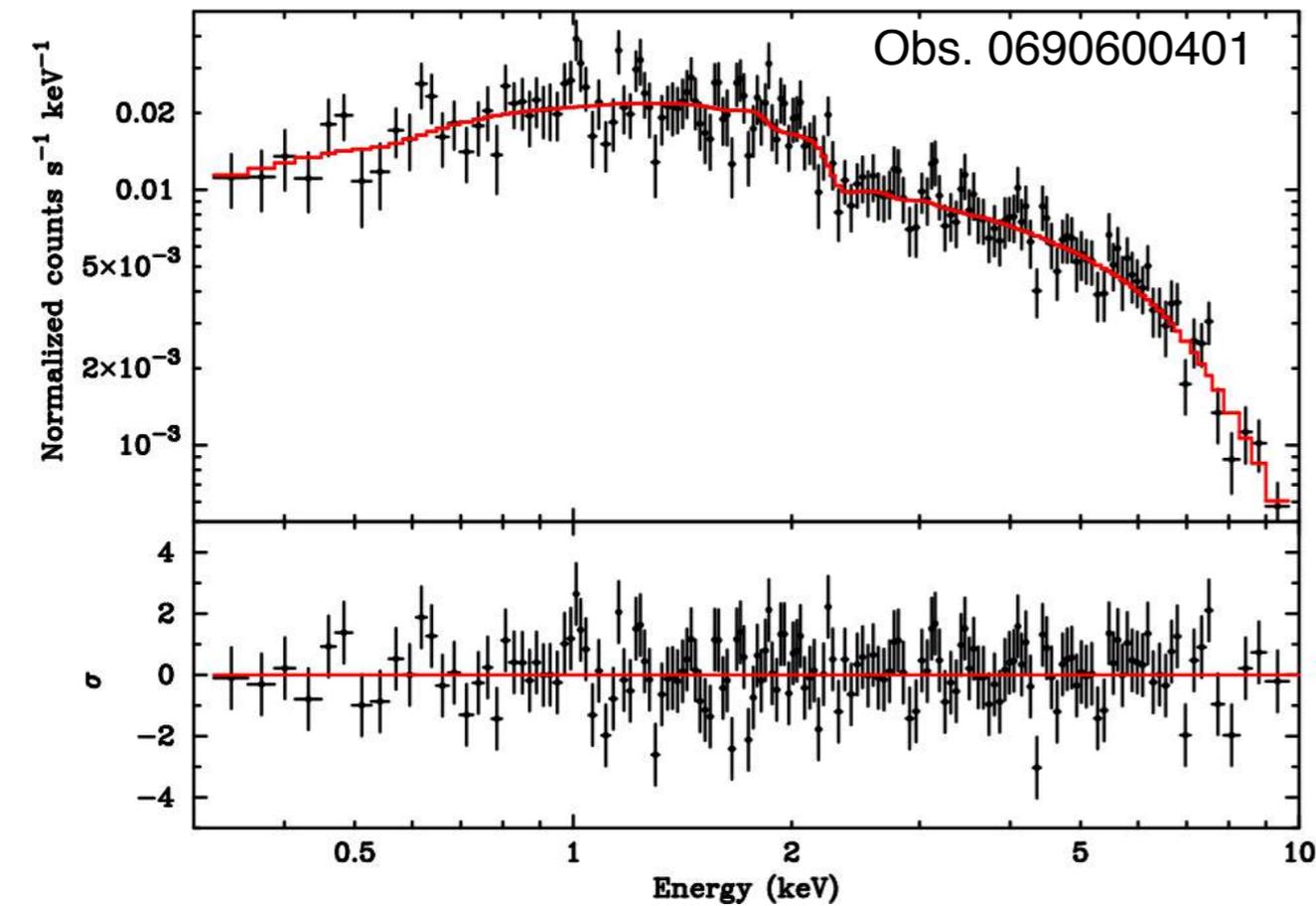
Spectral properties

Very bright:

$$L_x \sim (0.4 - 2.0) \times 10^{38} \text{ erg cm}^{-2} \text{ s}^{-1}$$

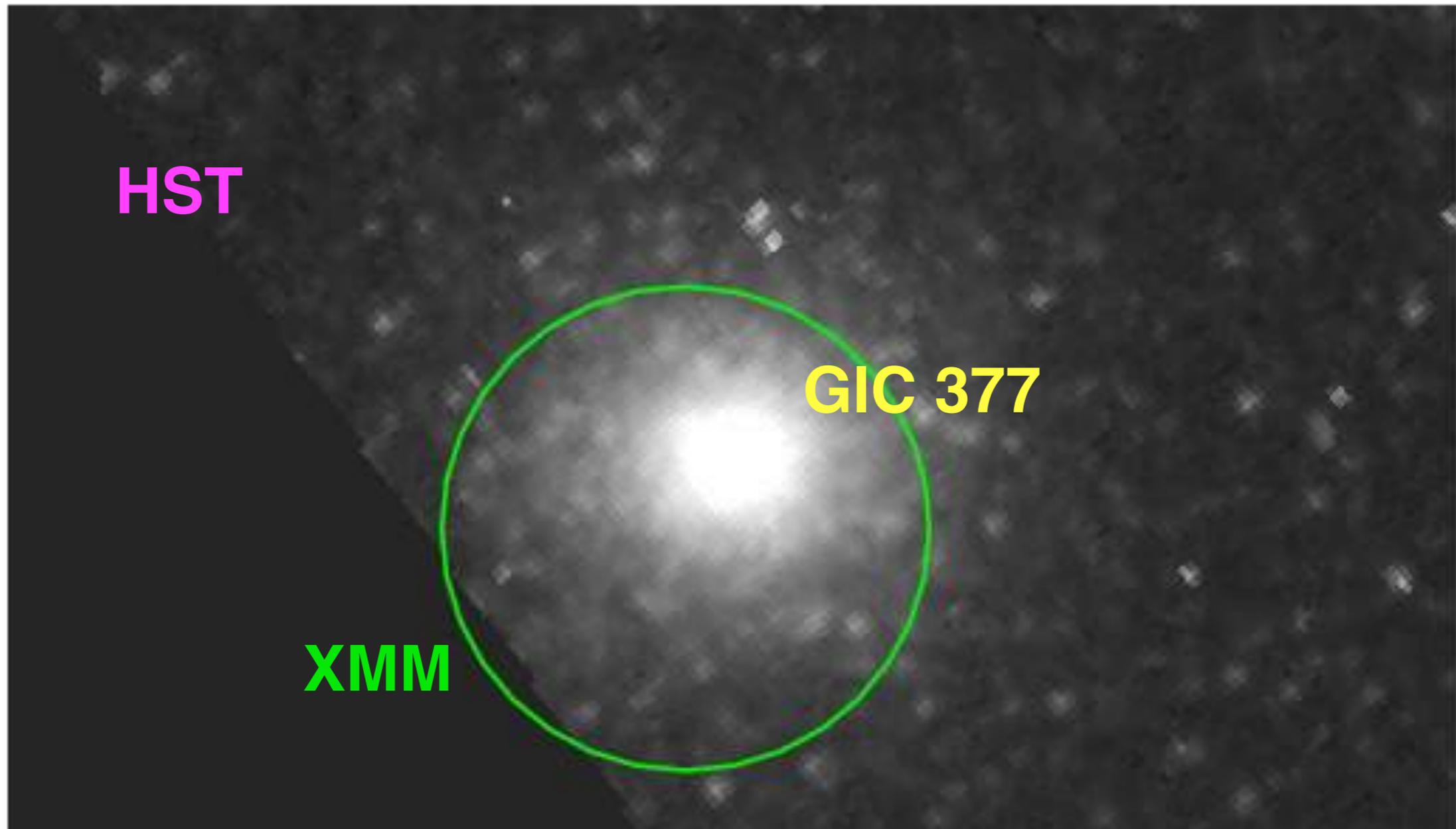
Most spectra can be fit by a
PL with $\Gamma \sim 0.3 - 1$

+ cutoff or thermal component for the highest quality spectra



Hint of a
'harder-when-brighter'
correlation

Optical Coverage

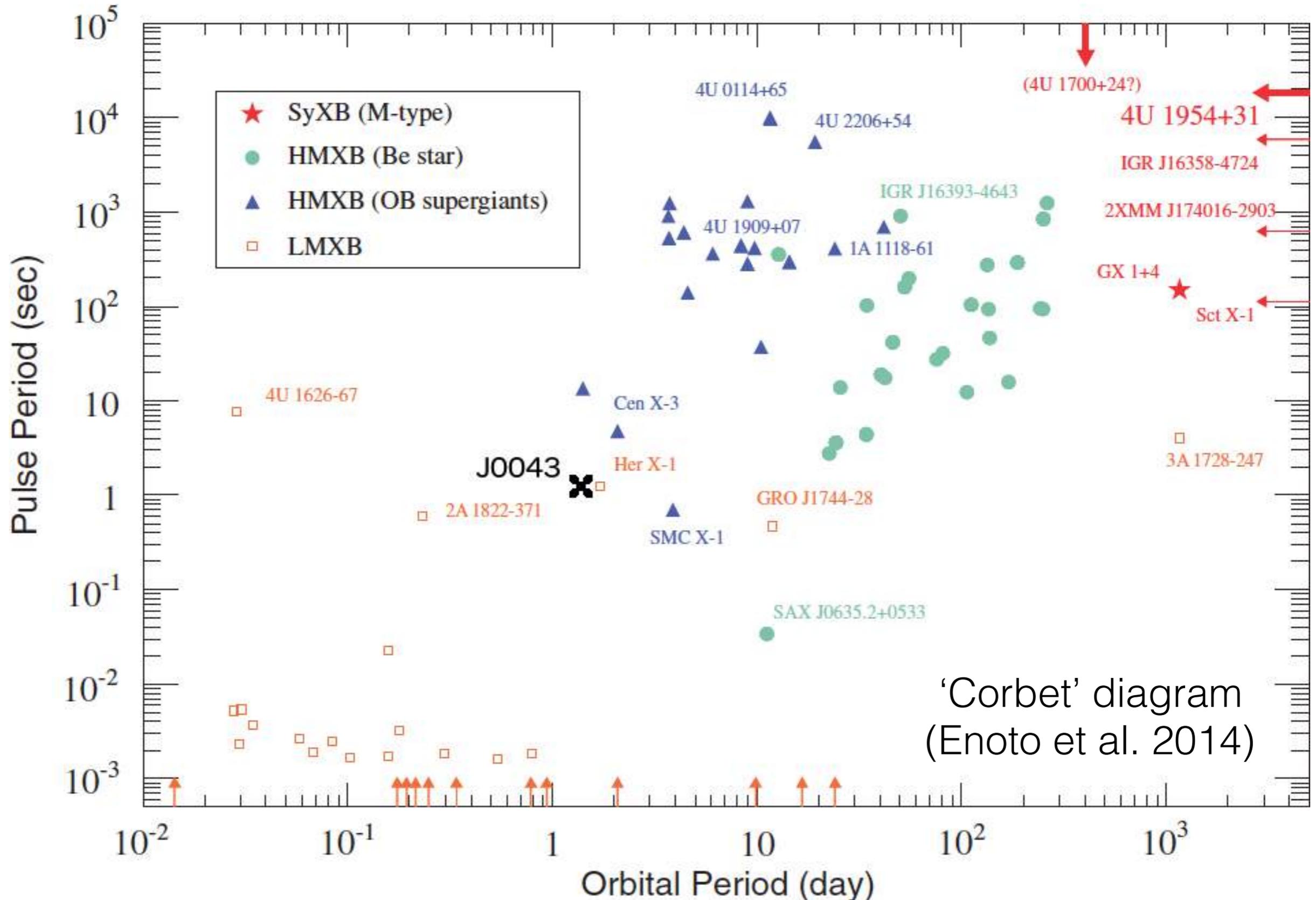


GIC 377 or $m_{F814W} > 21.5 / m_{F555W} > 22.0$
+ DM (24.45) + A_V (~0.2)

→ $M_V > -2.5$

The nature of the system

Accreting pulsar in M31 (variability, L_X , P_{dot})



The nature of the system

- (i) HMXB with a Roche lobe-filling massive star
- (ii) peculiar LMXB in or outside the GC
- (iii) 'intermediate-mass' XRB (like Her X-1)

3X J0043 was proposed as a HMXB (Shaw Greening et al. 2009) based on the hard X-ray spectrum and a $V = 17.2$ object $< 0.7''$ (Massey et al. 2006)

$$M_V > -2.5$$

No eclipses or occultations

A $> 8 M_{\odot}$ would require $i < 9^{\circ}$

(Short life $t_{\text{th}} < 10^5$ yr for $M > 7 M_{\odot}$; Karino 2016)

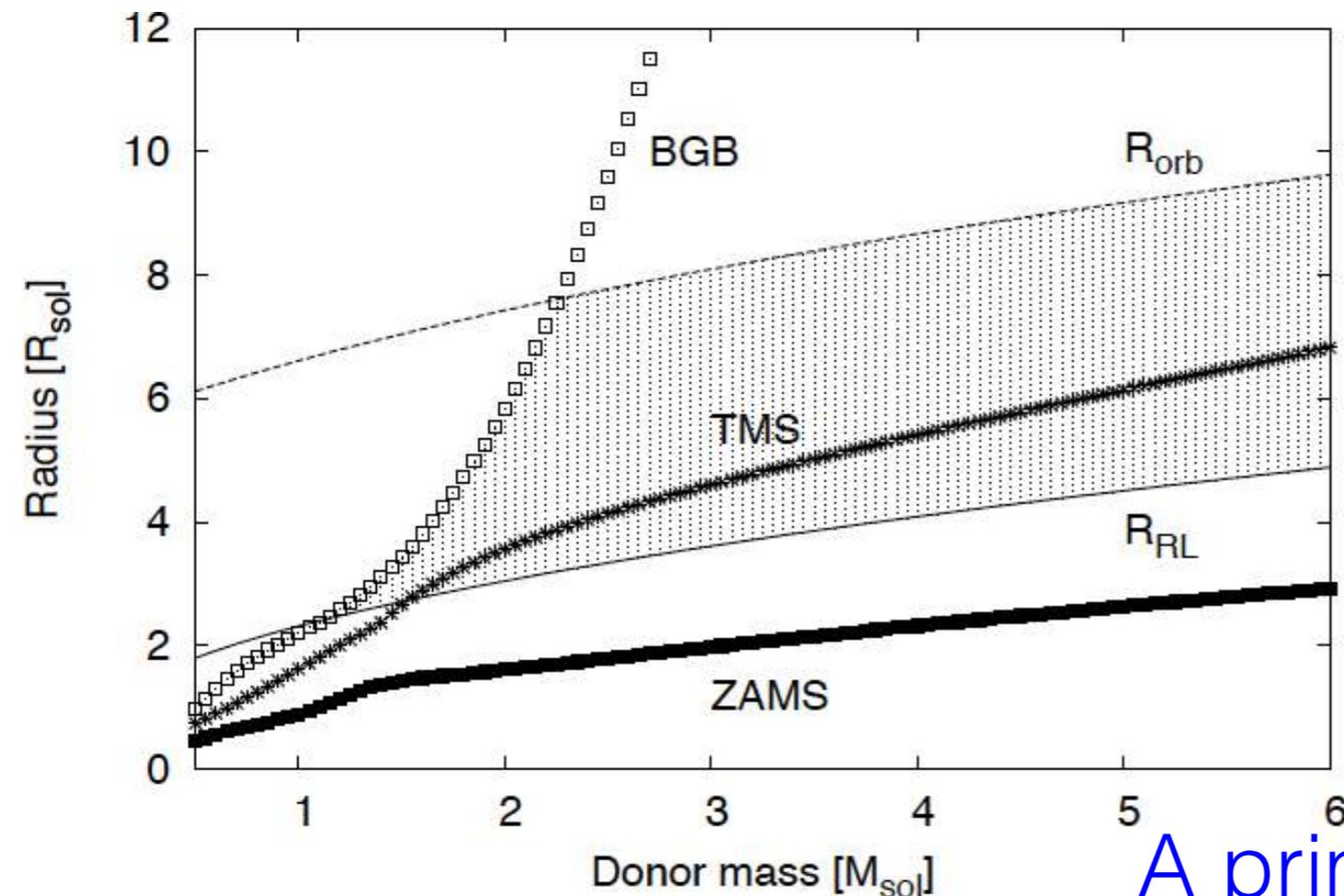
Very unlikely!

The nature of the system

- (i) HMXB with a Roche lobe-filling massive star
- (ii) peculiar LMXB in or outside the GC
- (iii) 'intermediate-mass' XRB (like Her X-1)

Unusually long period; some similarities with

- 4U 1822-37: 0.59 s / 0.23 d (Jonker+01)
- 4U 1626-67: 7.7 s / 0.03 d (Rappaport+77; Chakrabarty 1998)



A $<0.95M_{\odot}$ donor cannot evolve and expand to R_{RL} within T_H (27.9 Gyr for $0.8M_{\odot}$); if $<1.1M_{\odot}$, it needs to evolve into a red giant before filling R_{RL}

$B \sim 10^{12}$ G (equilibrium or accretion)
Unusual for a NS in a LMXB

(Karino 2016)

A primordial LMXB is disfavoured

The nature of the system

- (i) HMXB with a Roche lobe-filling massive star
- (ii) peculiar LMXB in or outside the GC
- (iii) ‘intermediate-mass’ XRB (like Her X–1)

Zolotukhin et al. 2017:

- Long-term $dP/dt = -7.1 \times 10^{-13} \text{ s s}^{-1}$: accretion started less than 1 Myr ago, a conventional MSP in $\sim 10^5 \text{ yr}$
- A binary recently formed in the GC by getting a $\sim 0.8 M_{\odot}$ star in a dynamical interaction
- If indeed $B \sim 10^{12} \text{ G}$, perhaps a NS formed via AIC

“Also in this scenario, however, the lower mass limit of $\sim 1.5 M_{\odot}$ for the donor could not be avoided, since this is dictated by the evolution time required to leave the main sequence and to expand up to Roche radius.” (Karino 2016)

The nature of the system

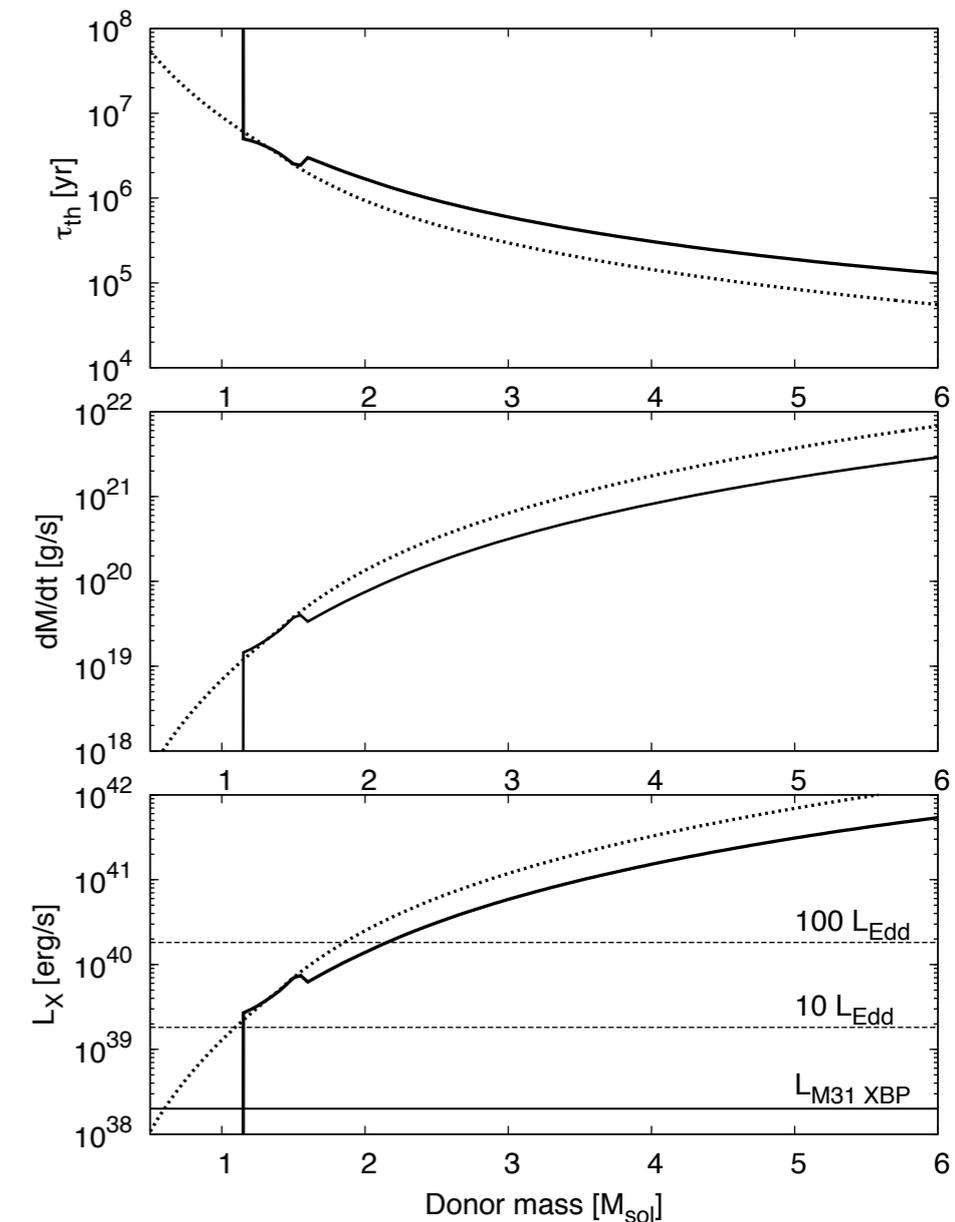
- (i) HMXB with a Roche lobe-filling massive star
- (ii) peculiar LMXB in or outside the GC
- (iii) 'intermediate-mass' XRB (like Her X-1)

Her X-1:

- 1.2 s / 1.7 d periods (Tananbaum+72)
- $\sim 2-M_{\odot}$ A star companion

3X J0043:

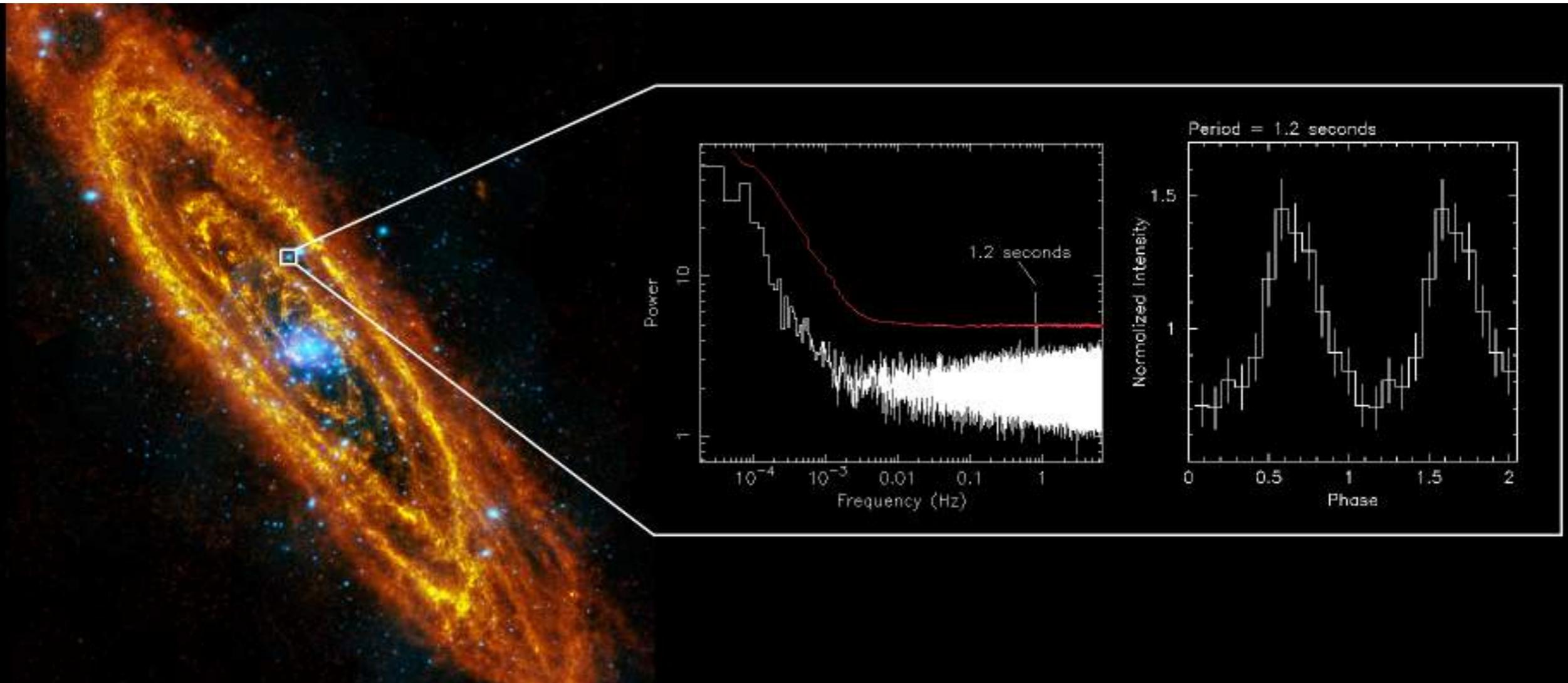
- very similar periods!
- $\sim 2-M_{\odot}$ B or later type companion is allowed by photometry
- high luminosity and high B would not be unusual
- OK with $> 1.5M_{\odot}$ companion ($\leq 2.5M_{\odot}$) from stellar evolution tracks by Karino16



Summary / The future

- The first detection of the spin (1.2 s) of a NS in M31
- An accreting NS in a 1.27-d binary system
- Two main viable scenarios: an IMXB (similar to Her X–1) or some ‘peculiar’ LMXB

Regardless of its true nature, it's certainly an interesting source!

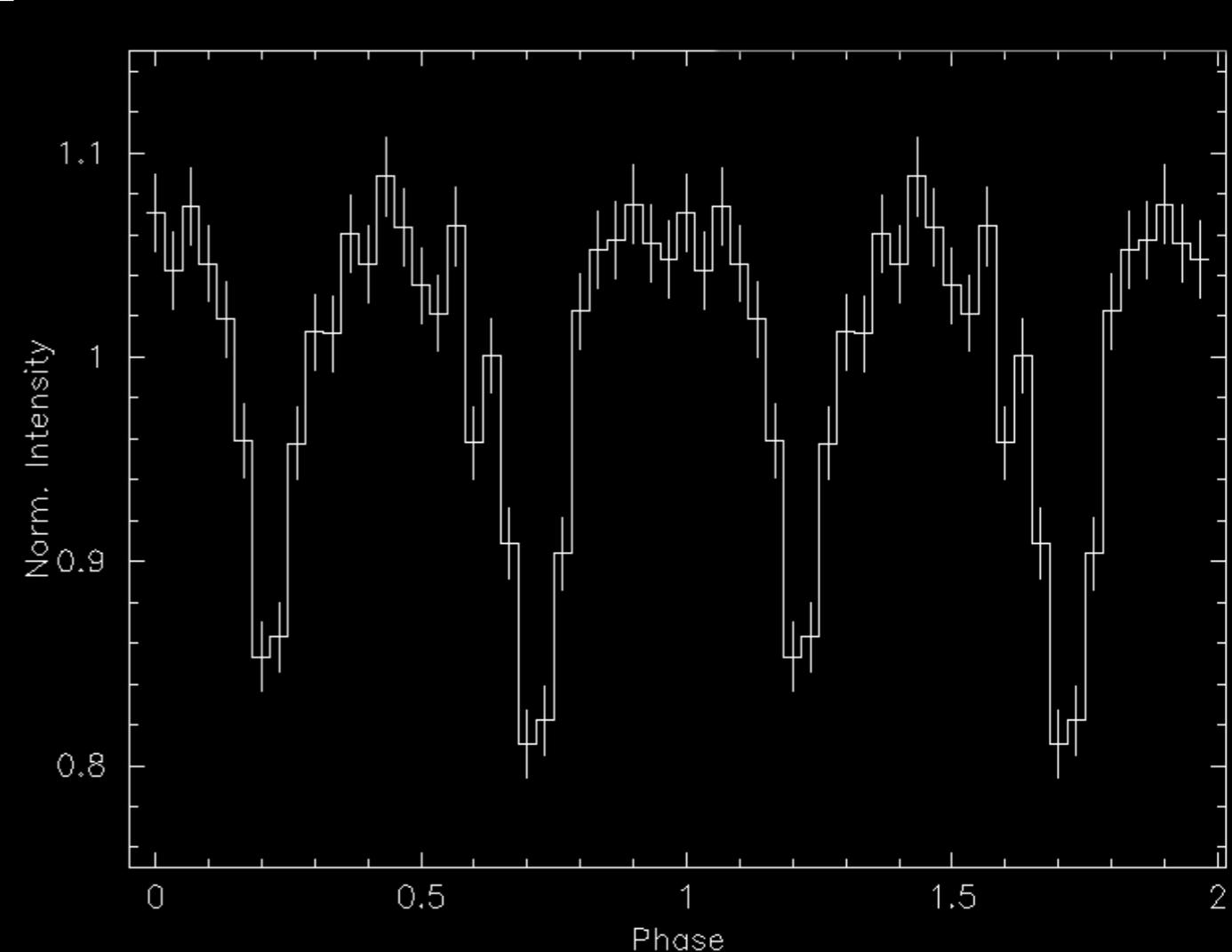
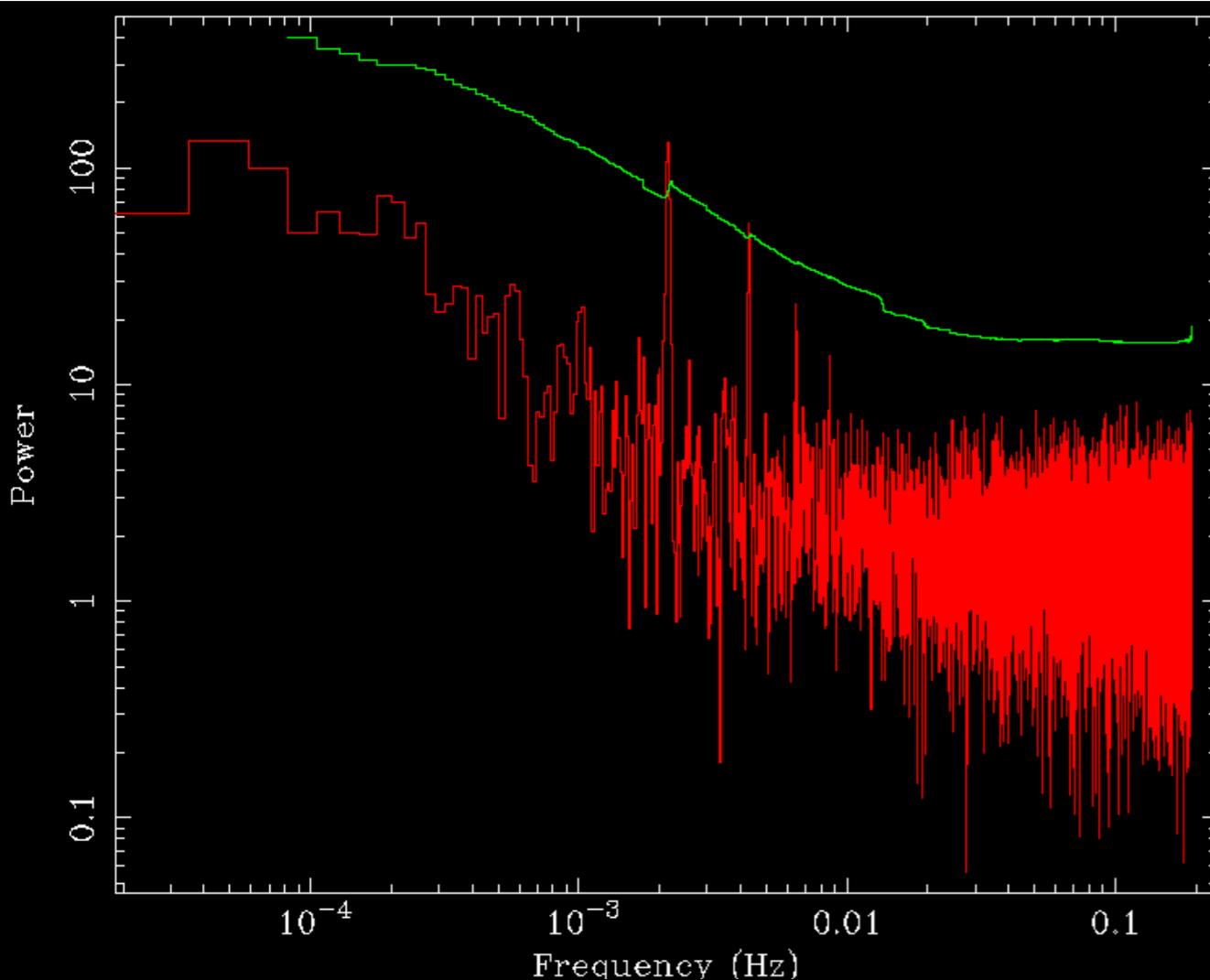


Summary / The future

XMM monitoring and timing could decipher it

Radio campaign at GBT

New results are coming from EXTraS, including
a new X-ray pulsator in M31!



Thanks for your attention!

Ciao Nanni



First PI of XMM's EPIC