A new detection of pulsations from an old ULX

Tim Roberts

Rajath Sathyaprakash (Durham)

Dom Walton (Cambridge), Felix Fuerst (ESA), Matteo Bachetti (Cagliari) Ciro Pinto (ESA), Fabien Grise (Penn State), Phil Kaaret (Iowa), Will Alston (Cambridge), Hannah Earnshaw (Caltech), Andy Fabian (Cambridge), Matt Middleton (Southampton), Roberto Soria (UCAS)
Ultraluminous X-ray sources

- **ULXs**: point sources in nearby galaxies with $L_x \gtrsim 10^{39}$ erg s$^{-1}$
- Most luminous extra-nuclear, non-explosive objects
- Eddington limit is $L_{Edd} = 1.3 \times 10^{38} (M/M_\odot)$ erg s$^{-1}$
- Implies big black holes ($\geq 10 M_\odot$); or super-Eddington accretion

*Kaaret, Feng & Roberts (2017)*
It’s got a pulse!

- Detections of pulsating ULXs are a paradigm shift → neutron stars
- Difficult to detect – large $\dot{P}$
- Find sinusoidal pulse profiles, $P \sim 1$ s, $\dot{P} \sim 10^{-11} \rightarrow 10^{-7}$ s s$^{-1}$, pulse fraction higher at high E, transient

Pulse detection in NGC 5907 (Israel et al. 2017), showing pre- and post-correction for large $\dot{P}$ ($\sim 10^{-9}$ s s$^{-1}$) in a ULX that goes up to ~ 500 times Eddington
New questions

- **Demographics**: fraction of ULXs hosting NS?
  - How do we distinguish NS from BHs?

- **Physics**: how does super-Eddington accretion work for high magnetic field NSs?

  - **Super-critical disc?**
    (e.g. Takeuchi et al. 2013)

  - **Magnetospherically-dominated accretion?**
    (Mushtukov et al. 2017)

  - **Hybrid model?**
    (Mushtukov et al. 2018)
XMM-Newton LP for NGC 1313

- > 700 ks of data to look for RGS wind signatures (Pinto et al., Walton et al. in prep.)

Accelerated pulsations search finds two periods with pulses (green shaded).

Data is light curve of NGC 1313 X-2, Sathyaprakash et al. (2019)
Weak pulsations

```plaintext
\[ \text{Leech power} \]

\[\text{Frequency [Hz]}\]

\[\text{Rate [s}^{-1}]\]

\[\text{Phase (cycles)}\]

\[\text{PF = (5.3 \pm 2)\%}\]

\[\text{PF = (6.4 \pm 2)\%}\]
```
Are they real pulsations?

- **YES**
- Detected by multiple methods
- Pulse period (~1.5s) & profile similar to other PULXs
- Monte Carlo sims – detecting two false periods with same $\Delta f$ no better than 1 in 10000 occurrence

Detection of pulses using epoch folding tool in HENDRICS. ($Z^2 > 40 \equiv 3\sigma$)
Orbital constraints

- Change in detected $f, \dot{f}$ between two detections is high – assumed orbital.
- Can rule out some orbital configurations for a 1.4 $M_\odot$ NS (black).
- X-ray properties suggest face-on – spin-orbit misalignment?

*Black regions show $\Delta \dot{f} < 8.5 \times 10^{-9}$ Hz s$^{-1}$ (top) and $\Delta f < 1.5 \times 10^{-3}$ Hz (bottom). Blue line shows upper limit on companion mass from local stellar population.*
An old PULX

- Large bubble nebula - $L_{\text{mech}} \sim 10^{40}$ erg s$^{-1}$ for $10^6$ years
- Still pulsing – $B$ field survives accretion!
- If $L_{\text{rad}} \sim L_{\text{mech}}$ then $\geq 1M_\odot$ accreted: but still NS?
- Most material lost in wind?
- Supports hybrid models

Hα emission from bubble nebula around NGC 1313 X-2 (Pakull, Lorentz Center talk, 2014)
Optical to X-ray SED

- Simultaneous *HST & XMM-Newton* observations for high & low X-ray fluxes
- Optical emission doesn’t change
- Dominated by star? Cf. P13, another PULX

**Fits show either unusually high reprocessed fraction; or another, likely stellar, component. Note also UV excess – outermost part of wind (cf. Poutanen et al. 2007)?**
More orbital constraints

- Reprocessed emission required in fits, out to NIR
- Implies big accretion disc ($10^6 R_g$)
- Rules out BH accretor (too big for Roche lobe); fits with NS! Consistent with pulsations
Summary

- NGC 1313 X-2 – fifth reported PULX
- Properties similar to other PULXs – but pulsations fainter
- If changes in $f, \dot{f}$ are orbital – possible spin-orbit misalignment
- Bubble nebula says ULX old – but still pulsing so B field not buried, NS not collapsed to BH – material lost in wind? *Hybrid physical model*
- Optical light dominated by companion star