CATS @ BAR

Chandra Acis Timing Survey @ Brera And Rome astronomical observatories

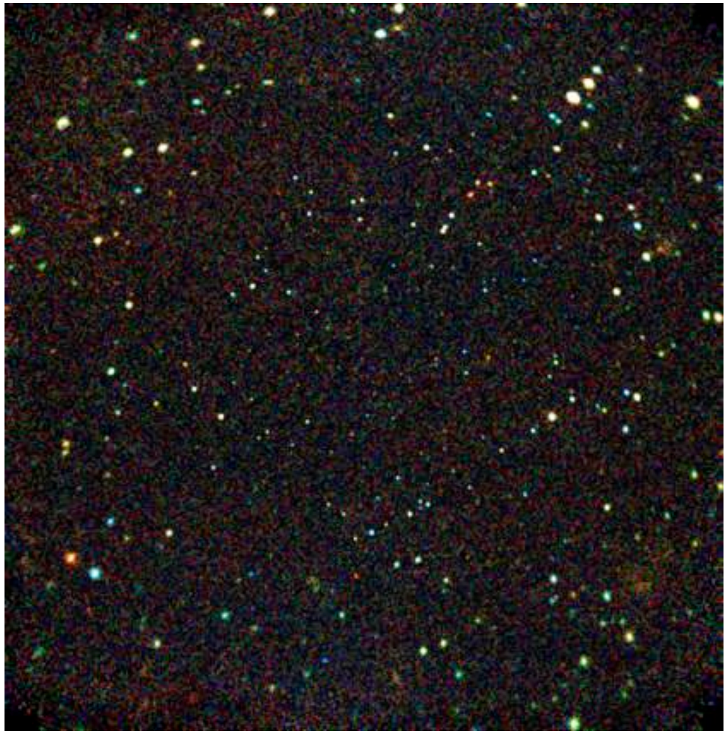
Gian Luca Israel,
G. Rodríguez

PE, Lara Sidoli

A. Moretti, P. D'Avanzo,
S. Campana

J. P. Halpern (Columbia U.), M. J. Coe (U. Southampton), N. Masetti (IASF Bo), E. Mason (STScI), D. Götz (CeA), L. Zampieri, M. Mapelli (OA Padova), V. D'Elia (ASI SDC)

Thousands of X-ray unidentified sources



CXO DFS - CXC/NASA/Giacconi

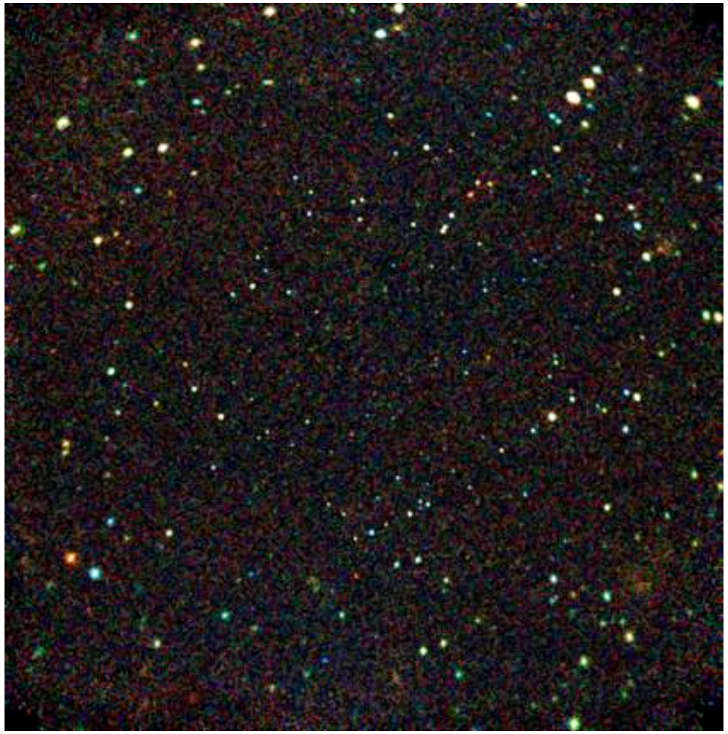
When a new X-ray mission is launched, many serendipitous sources of unknown nature are usually discovered

Most of them, especially the faintest ones, can remain unidentified for years

~50 000 objects from EXOSAT, ROSAT and ASCA

>10 times more with XMM, Chandra and Swift

Thousands of X-ray unidentified sources



CXO DFS - CXC/NASA/Giacconi

When a new X-ray mission is launched, many serendipitous sources of unknown nature are usually discovered

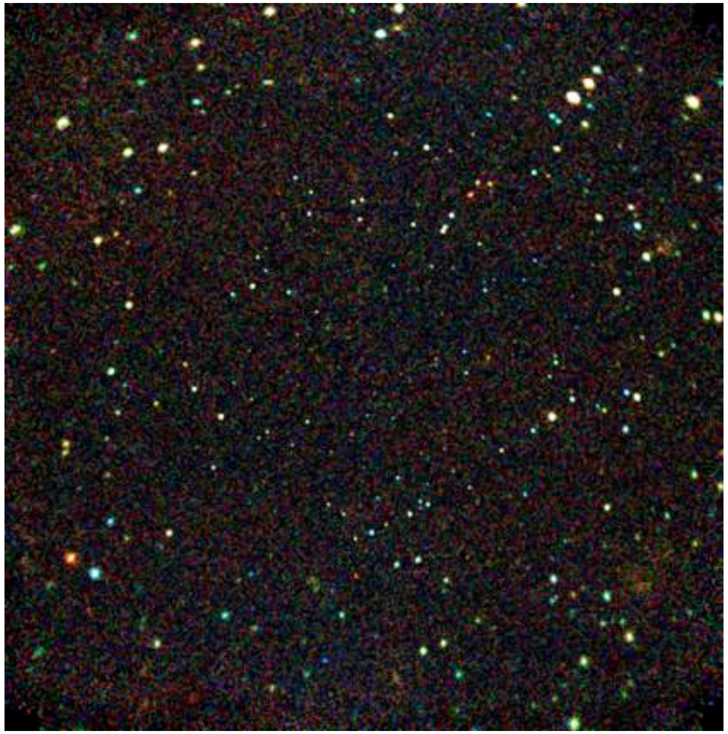
Most of them, especially the faintest ones, can remain unidentified for years

~50 000 objects from EXOSAT, ROSAT and ASCA
>10 times more with XMM, Chandra and Swift

Fundamental to understand the different populations of Galactic and extragalactic X-ray sources

Many interesting sources might lurk among them

Thousands of X-ray unidentified sources



CXO DFS - CXC/NASA/Giacconi

When a new X-ray mission is launched, many serendipitous sources of unknown nature are usually discovered

Most of them, especially the faintest ones, can remain unidentified for years

~50 000 objects from EXOSAT, ROSAT and ASCA
>10 times more with XMM, Chandra and Swift

The detection of pulsations is key in understanding the nature of a source!

X-ray pulsators

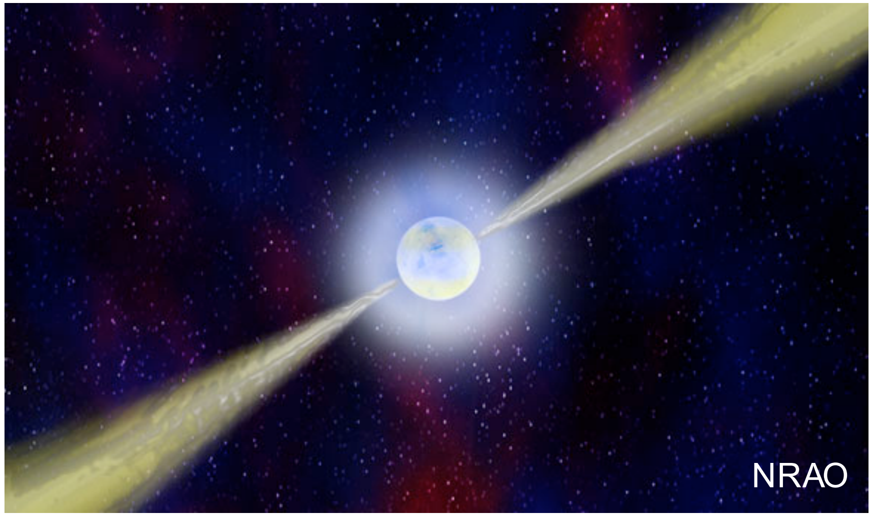
Coherent signals in general reflect the rotation of a compact object or the orbital motion in a binary system

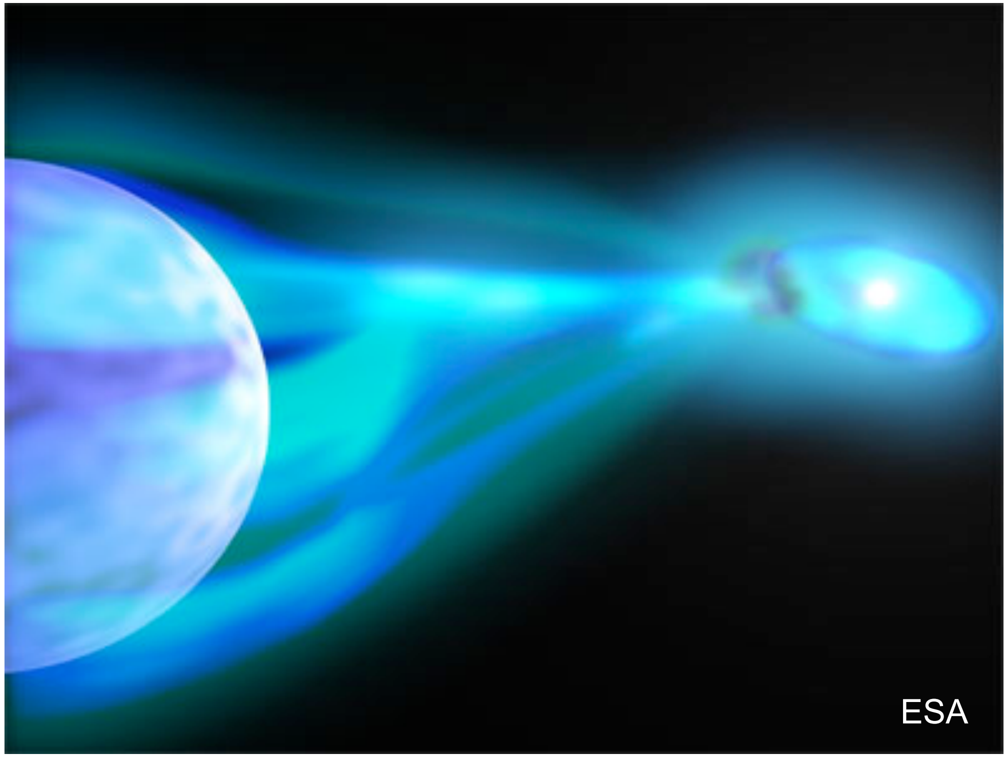
Rotation

Accreting magnetic NSs

Isolated NSs
(rotational, thermal or magnetic energy)

Magnetic WD systems
(e.g. polars and intermediate polars)



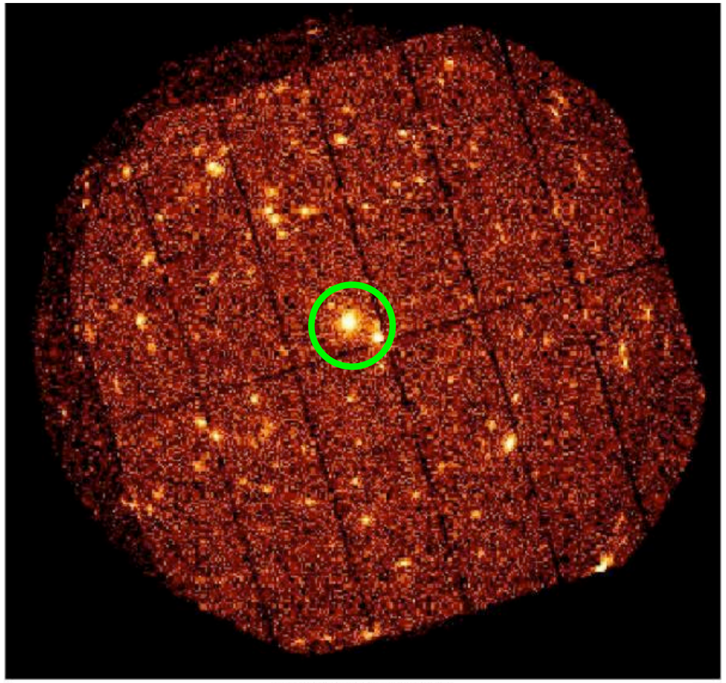


Orbital motion

Essentially any combination with ≥ 1 compact objects

X-ray pulsators

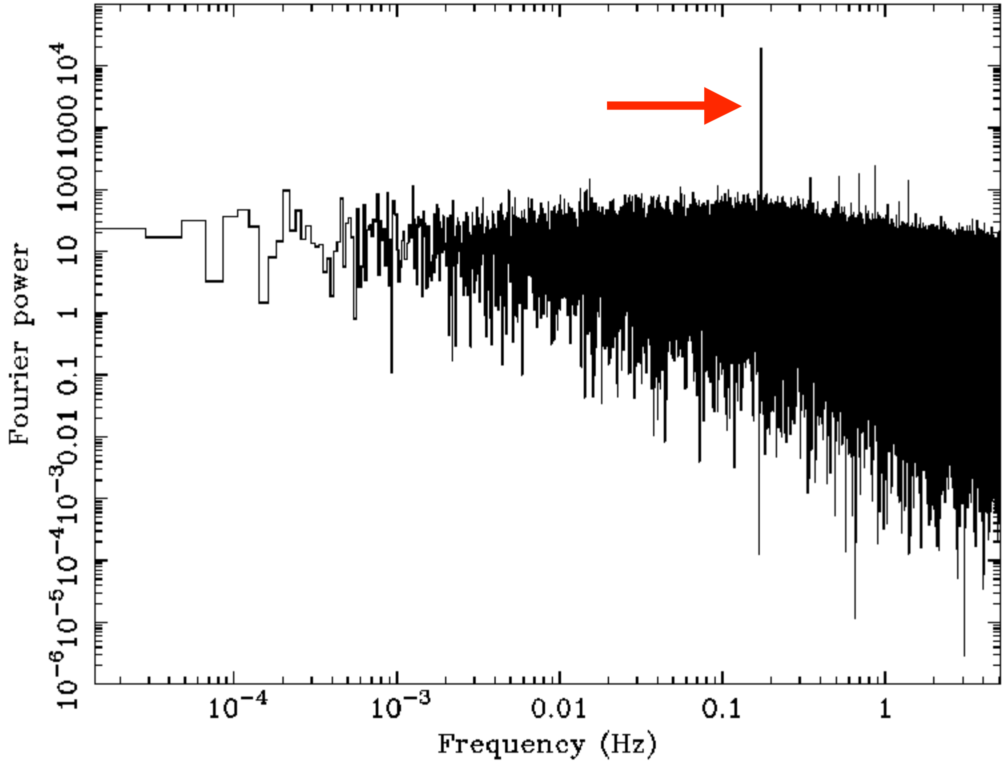
In general, modulation is discovered through timing analysis of the source targeted by an observation



Open stellar cluster: Praesepe

Image courtesy of R. Pallavicini, Osservatorio Astronomico di Palermo, Italy

European Space Agency



~50 000 objects from EXOSAT, ROSAT and ASCA

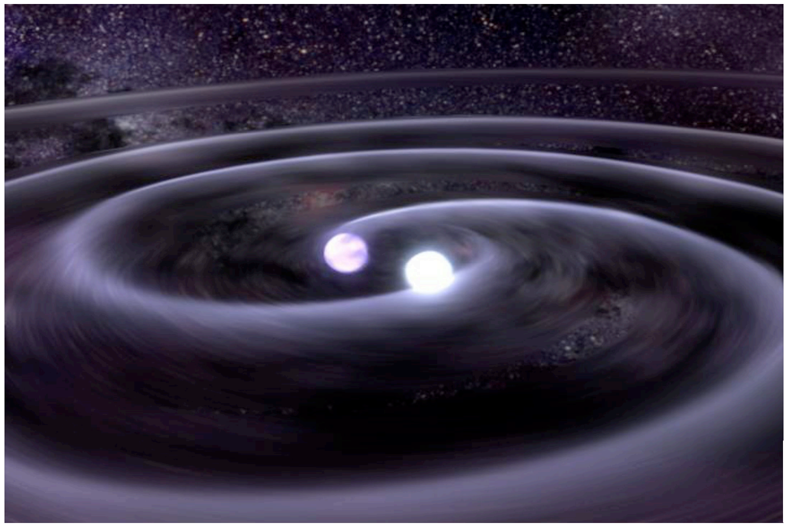
>10 times more with XMM, Chandra and Swift

Enormous discovery space in serendipitous sources

Previous searches (by GLI)

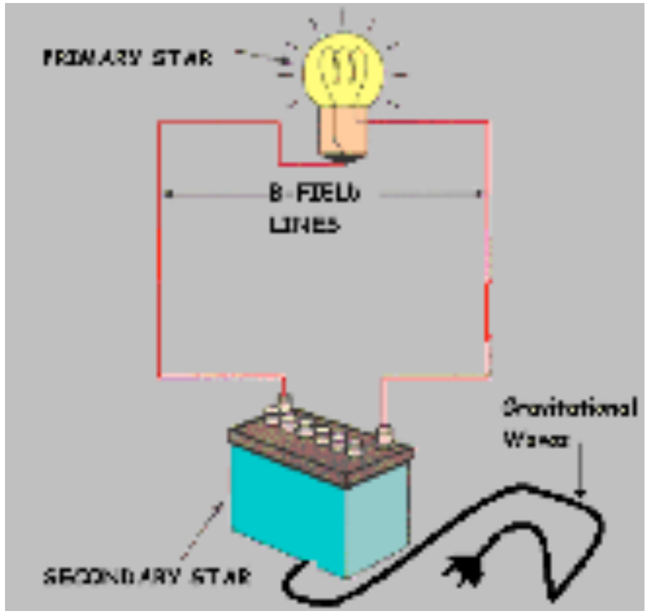
- **EXOSAT**: detection of pulsations from 4U 0142+614, prototype of the AXP class (Israel et al. 1994)
- **ROSAT PSPC**: detection of pulsations form HD 49798, a unique object (likely a massive WD) in a post common envelope phase (Israel et al. 1996, Mereghetti et al. 2009); likely to produce a Ia SN
- **ROSAT HRI**: detection of HM Cnc, a double degenerate (2-WD) binary with the shortest orbital period known (5.4 min!); likely a new emission mechanism (unipolar induction) identified (Israel et al. 1999, 2002)
- **SWIFT XRT (PC)**: ~3000 light curves, 6 new X-ray pusators

GSFC/D. Berry



RX J0806.3+1527
aka HM Cnc

aka 'The Stinker'



SDO/GLI

CATS @ BAR

Chandra and XMM provides large throughput and good psf

Chandra vs XMM

Pros  Cons

✓ very low bkg level, better resistance to proton flares
✓ well suited to study faint sources (high S/N)
✓ long pointings in (very) crowded regions
✓ superbly maintained machine

▪ Long sampling time (3.2 s in most pointings)

- dithering oscillations around the on-axis direction
- smaller effective area

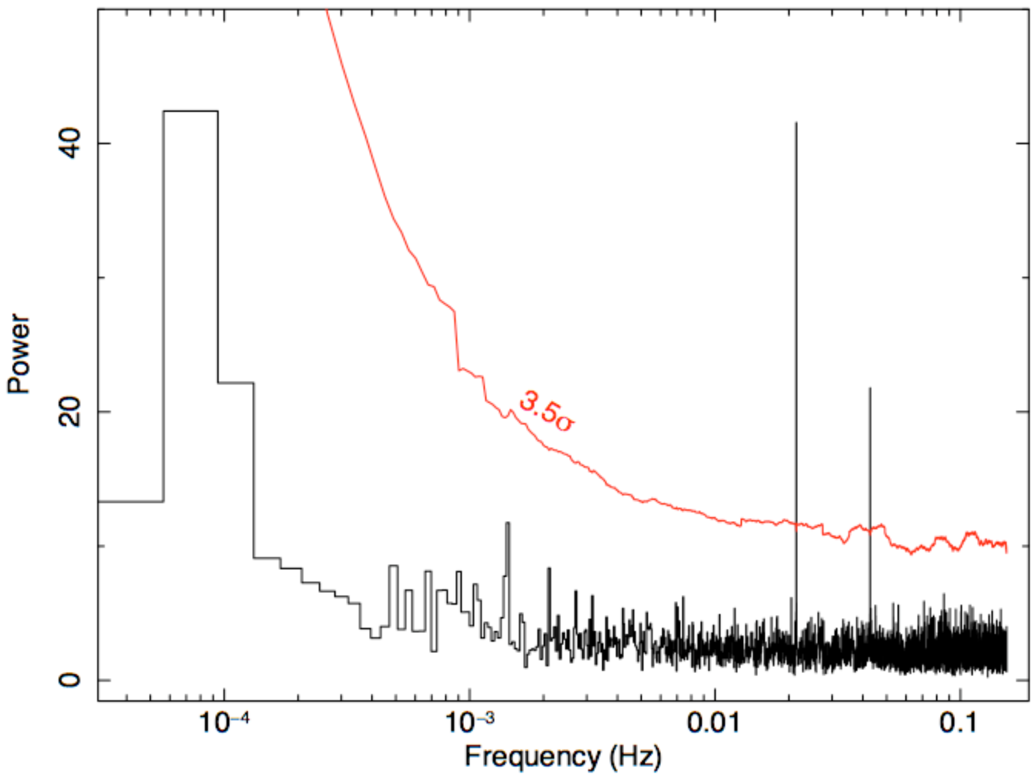
We started with Chandra,
but XMM is definitely better suited for timing

CATS @ BAR

C-shell/Fortran automatic pipeline developed for the ACIS archive

Main steps are:

- data retrieving
- exposure map creation and source detection (wavedetect)
- FFT search for signals in sources with >150 events (following Israel & Stella 1996)
- assessment of signal goodness (peak statistics, instrumental vs real, dither_region ciao task)

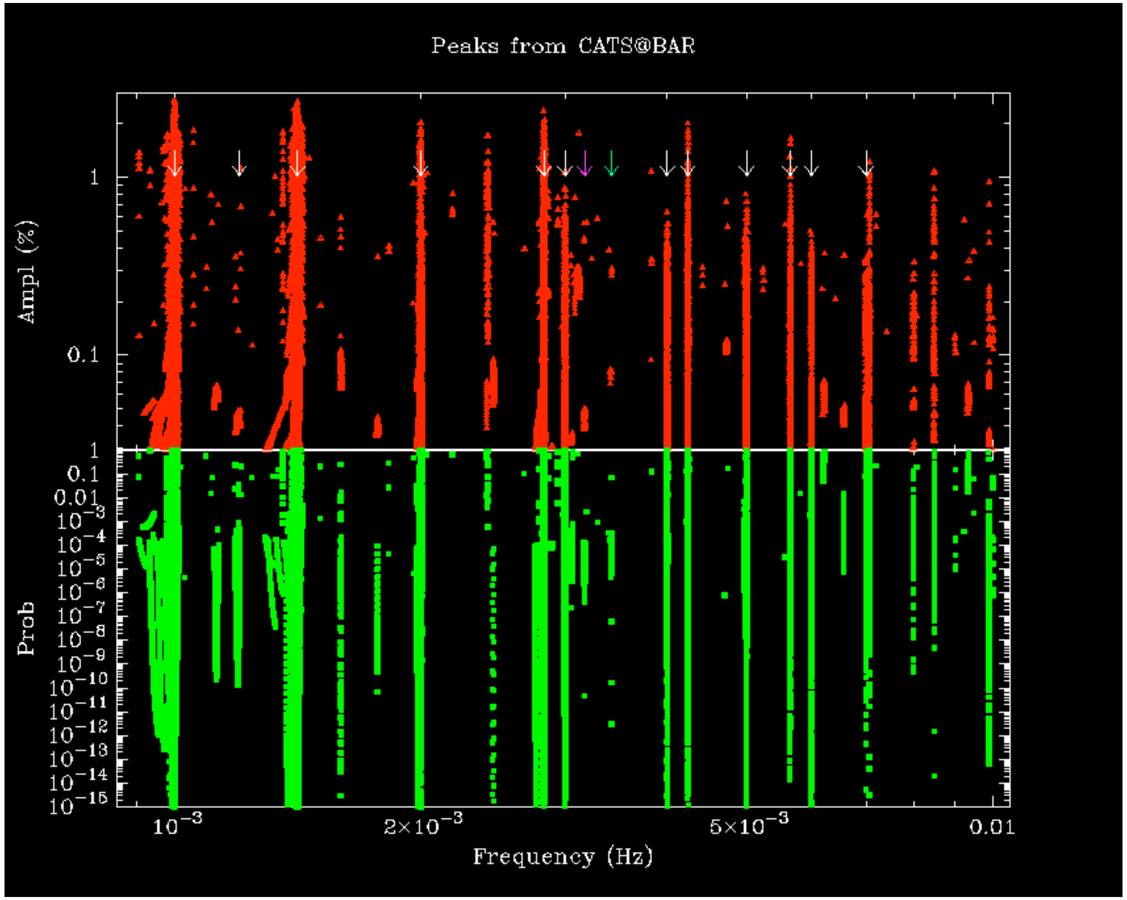


CATS @ BAR

C-shell/Fortran automatic pipeline developed for the ACIS archive

Main steps are:

- data retrieving
- exposure map creation and source detection (wavedetect)
- FFT search for signals in sources with >150 events (following Israel & Stella 1996)
- assessment of signal goodness (peak statistics, instrumental vs real, dither_region ciao task)



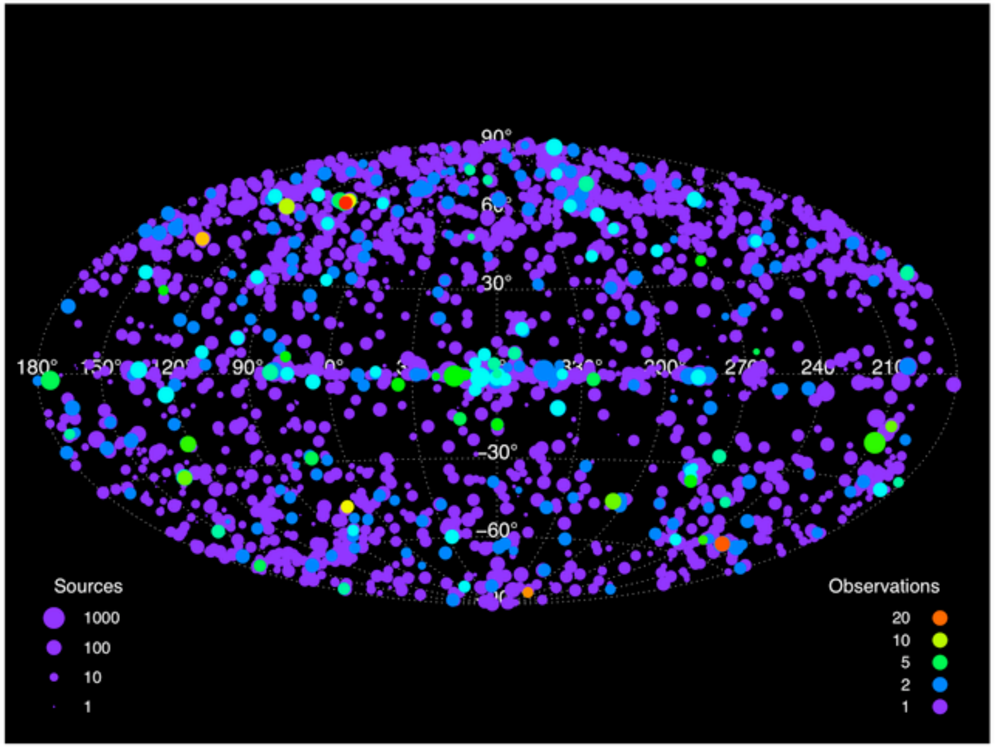
By-product: a detailed mapping of the spurious signals in the ACIS

A few numbers

First run in June 2012. About 9000 public observations (01 Sep 2013) in the Chandra ACIS archive (no CC or TG data considered), ~3 Tb of data

About 410,000 light curves created, about 100,000 of which with more then 150 photons

120 days of computing time on a 2.8 GHz Xeon processor with 16 Gb of RAM (no optimization was considered)



NASA/CXC

~$2x10^9$ trials in the FFTs (on average, ~20,000 Fourier frequency per FFT)

~150,000 peaks above 3.5s (or the single FFT) found

145,000 from spurious signals (~97%)

4000 from already known pulsators

1000 from new candidate pulsators

The new pulsars

30–35 new X-ray pulsators discovered so far (1 Sep 2013), many of which further confirmed by archival XMM, Swift and ROSAT observations

b	id	notes	Class	Obs@	Period
-44.895741	?		CV?		8650
-43.958552	O	transient/xmm	BeXRB		50.67
-43.823395	O	transient	BeXRB	EI	292
-3.740629		xmm			4775.97
-28.931584		xmm			43120
1.680012		xmm			1526
74.859600	---	xmm	LMXB?		25902.8
74.310859		da indagare			~2000
-3.782264		xmm			6379
-3.788787		xmm	IP CV		64166/6120
4.235116		ok prop			12450
20.223594					5500
-0.119908		xmm			5690
1.323674		xmm			5821
36.150970	O	xmm	CV	L	5674
7.213368					11950
-4.255600		xmm			3080
4.549199		1axaf			~5000
6.744985		xmm?			15300
5.843645		1axaf			4790
1.248932		da indagare			~4000
0.194788		da indagare			16000
0.433257		xmm			6482
-2.057786		swift(pos)			4912
-11.400707		segnale spurio?			5930
-0.892220		xmm/swift			407.8
-11.374931		da indagare			~1500
-11.376952		da indagare			8100
0.085768		xmm variabile			6366
-0.020245	O	xmm	NS?	L	36100
-0.468706					5930
4.998250		1axaf		X	5550
-8.389437	O	xmm variabile	Polar CV	B	6988.21
6.320085		ok prop			9995
-12.951307		ok prop			14100
2.861432	O	swift	HMXRB	NB	46.6

Periods between 8 s and 18 hr, not homogeneously distributed

Mostly CVs and HMXBs

Follow ups with XMM, VLT, NOT, NTT, CTIO, LBT, TNG …

Accretion mechanisms

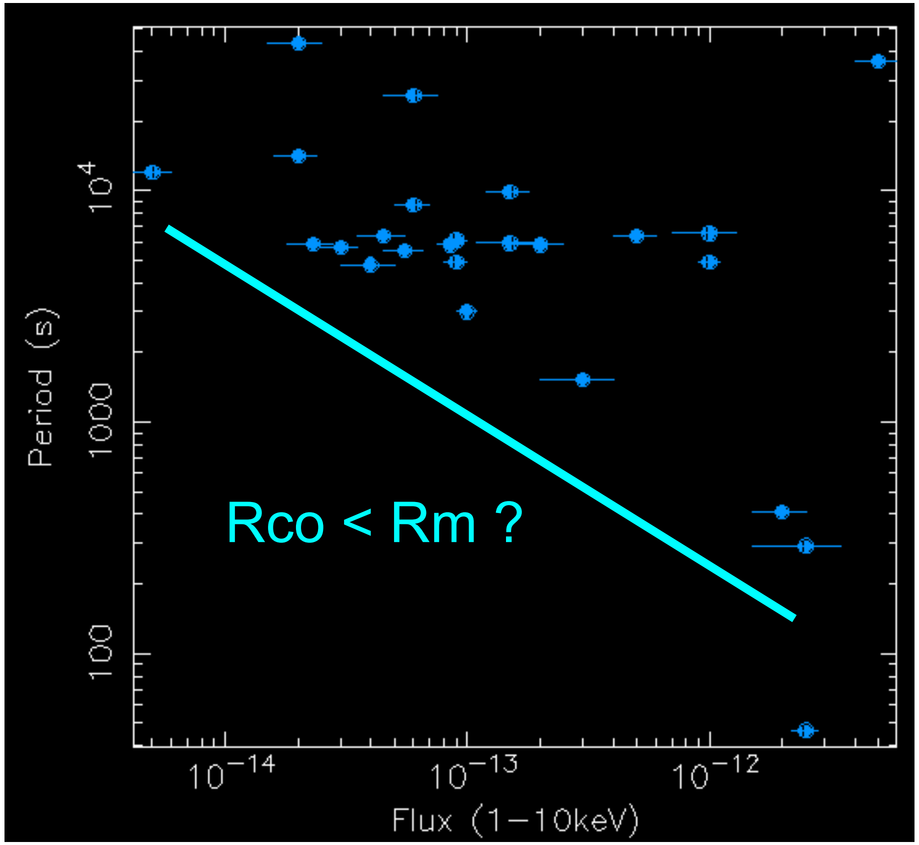
One of the aim of the search is to extend the luminosity interval over which the physics of the (accretion) emission mechanism can be investigated

At low luminosities (low accretion rates Mdot) only in NS with long spin periods and/or low magnetic fields (Rco > Rm), so that the matter can reach the NS surface at polar caps and spin pulses can be detected

Though this is a widely assessed theoretical scenario, so far it has not been possible to explore the low luminosity tail of the distribution of accreting compact objects

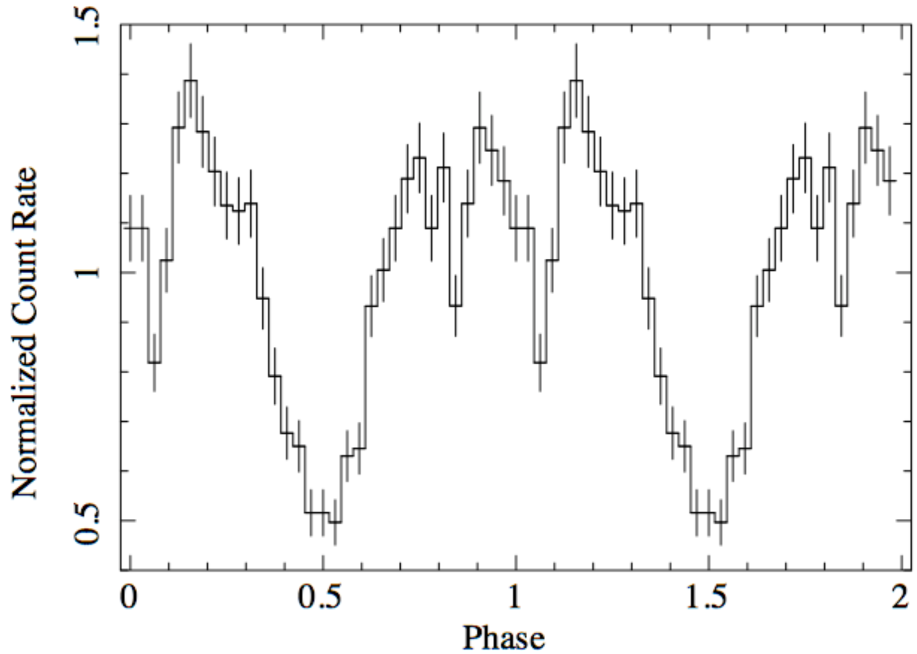
Hints for an anti-correlation between flux and period: we did not detect low-flux, short-period pulsators

But, follow-up observations for WD vs NS classification and distances are needed



Individual sources – 1

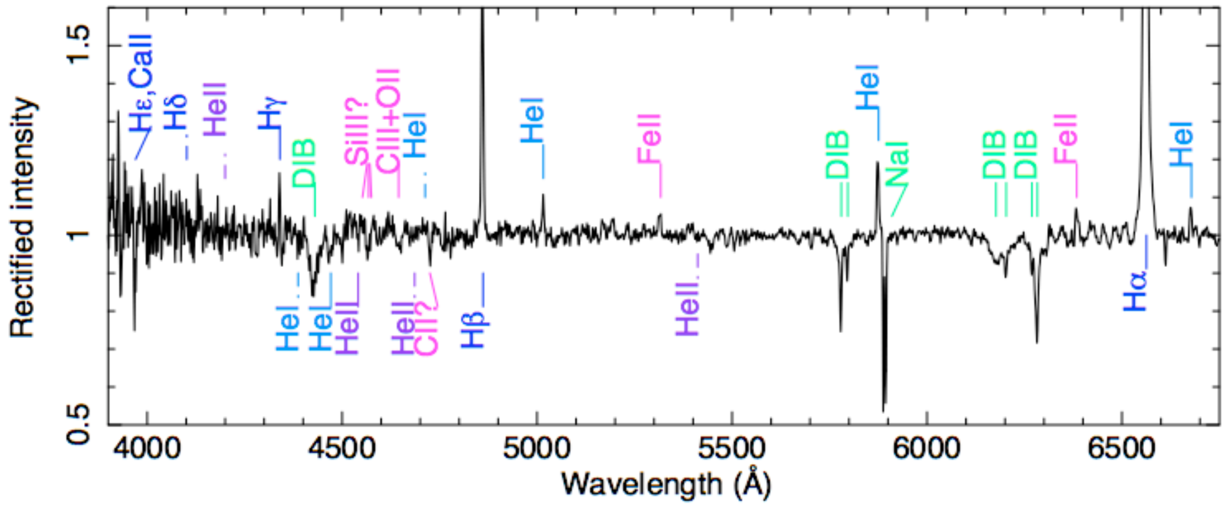
1RXS J225352.8+624354
(Esposito, Israel, Sidoli et al. 2013b)



Hard X-ray (INTEGRAL) source
B0-1 III-Ve star at 4–5 kpc
(Perseus Arm)

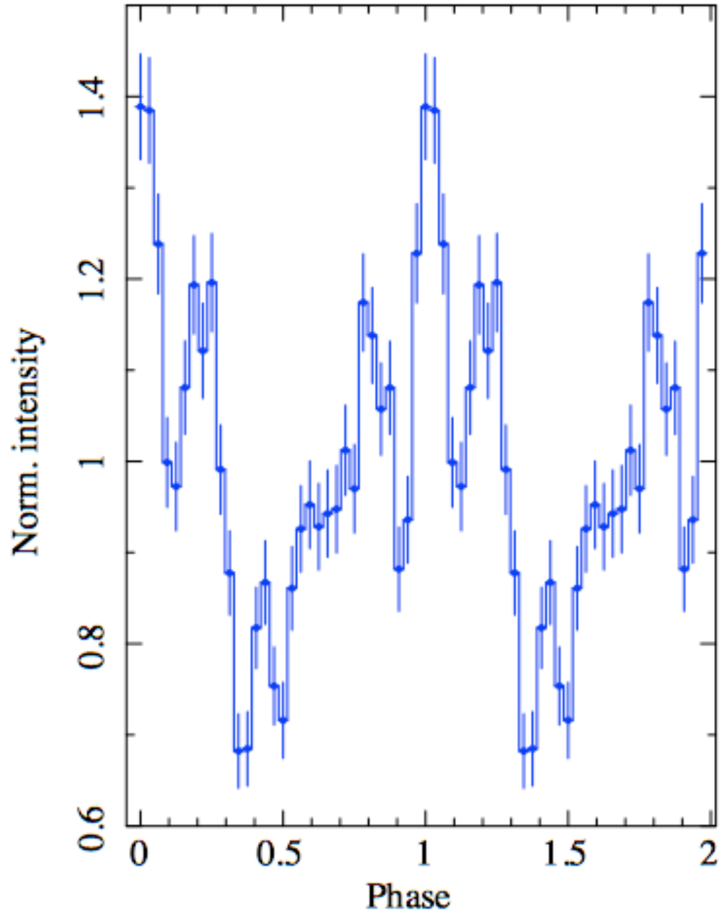
P = 46.67 s, Pdot = 1.3×10^{-9} s s^{-1}
L ≈ 10^{34} erg s^{-1}

New member of the sub-class of low-luminosity, long-orbital-period, persistent Be/X-ray pulsars in a wide and circular orbit (similar to X Persei)



Emerging population of persistent low-luminosity Galactic HMXBs accreting from B main-sequence donors (1–10% of the unidentified Galactic X-ray sources with L < 10^{35} erg s^{-1})

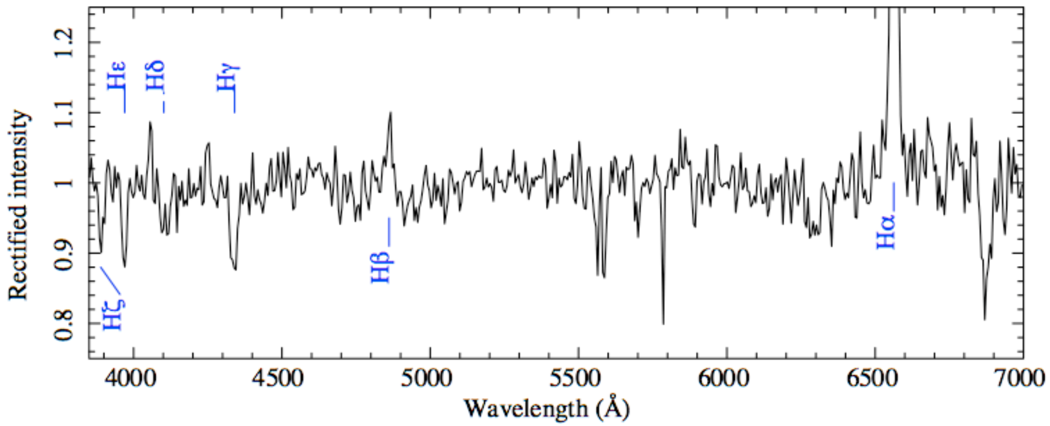
Individual sources – 2

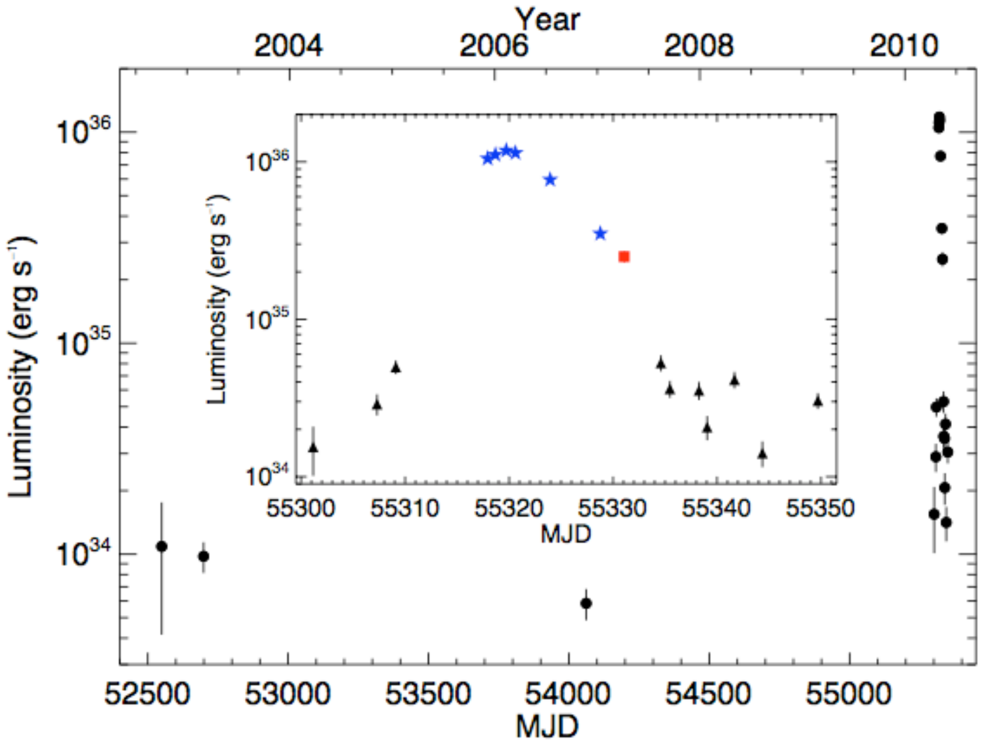


CXOU J005047.9–731817
(Esposito, Israel, Sidoli et al. 2013c)

The 1st of 3 new Be XRBs in the SMC discovered by CATS @ BAR

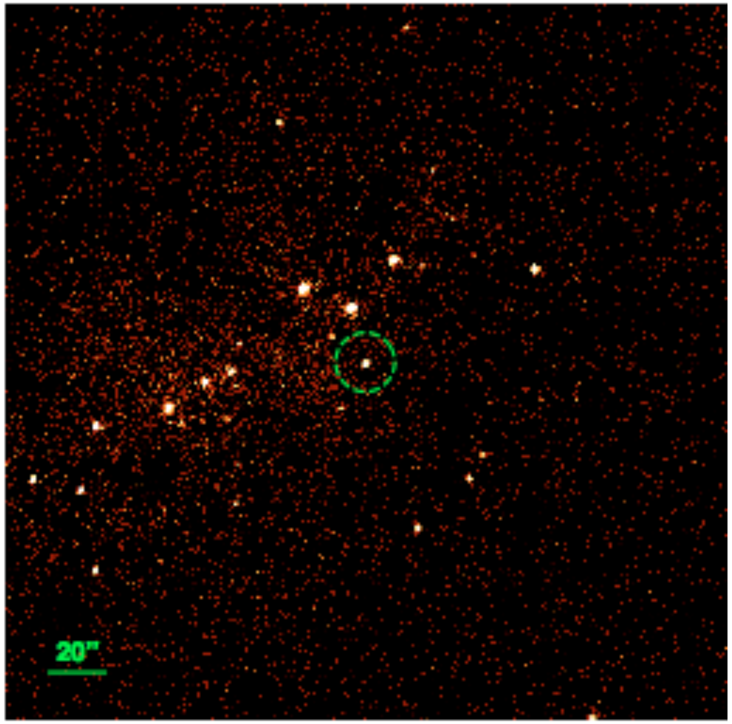
An entire type I burst fortuitously recorded by Chandra in 2010 Apr–May





A 6.4 hr BH binary in NGC 4490

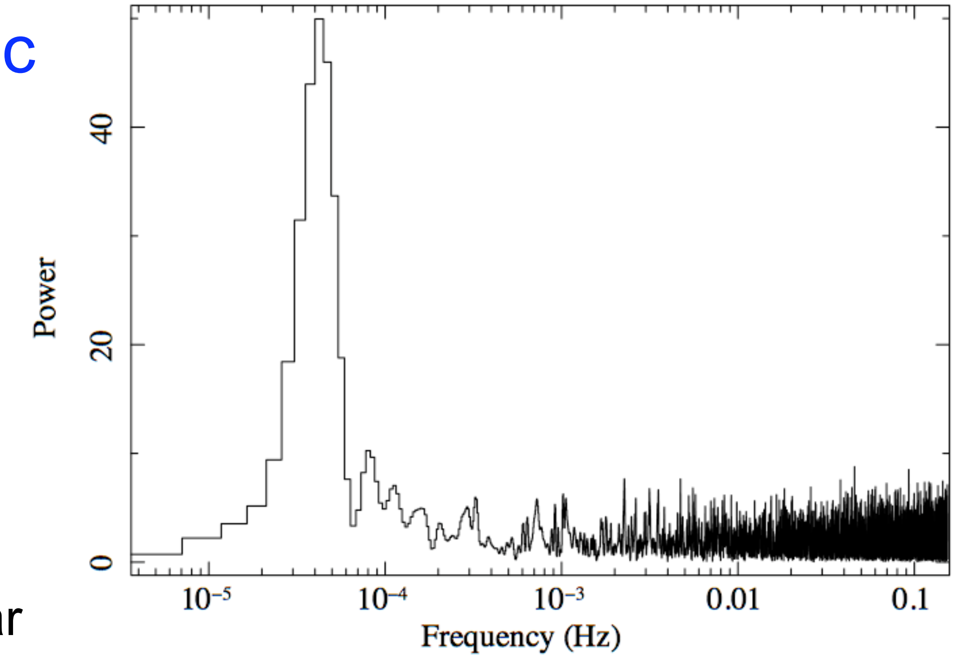
CXOU J123030.3+413853 (Esposito, Israel, Sidoli et al. 2013d)



NGC 4490 is a star-forming (5.5 $M_\odot$ yr^{-1}), low-metallicity spiral galaxy interacting with its irregular companion NGC 4485

D = 8 Mpc

P = (6.4 ± 0.1) h



Multiple CXO observations, confirmed by XMM

Only extragalactic CATS @ BAR source so far

A 6.4 hr BH binary in NGC 4490

P = (6.4 ± 0.1) h, 90% PF

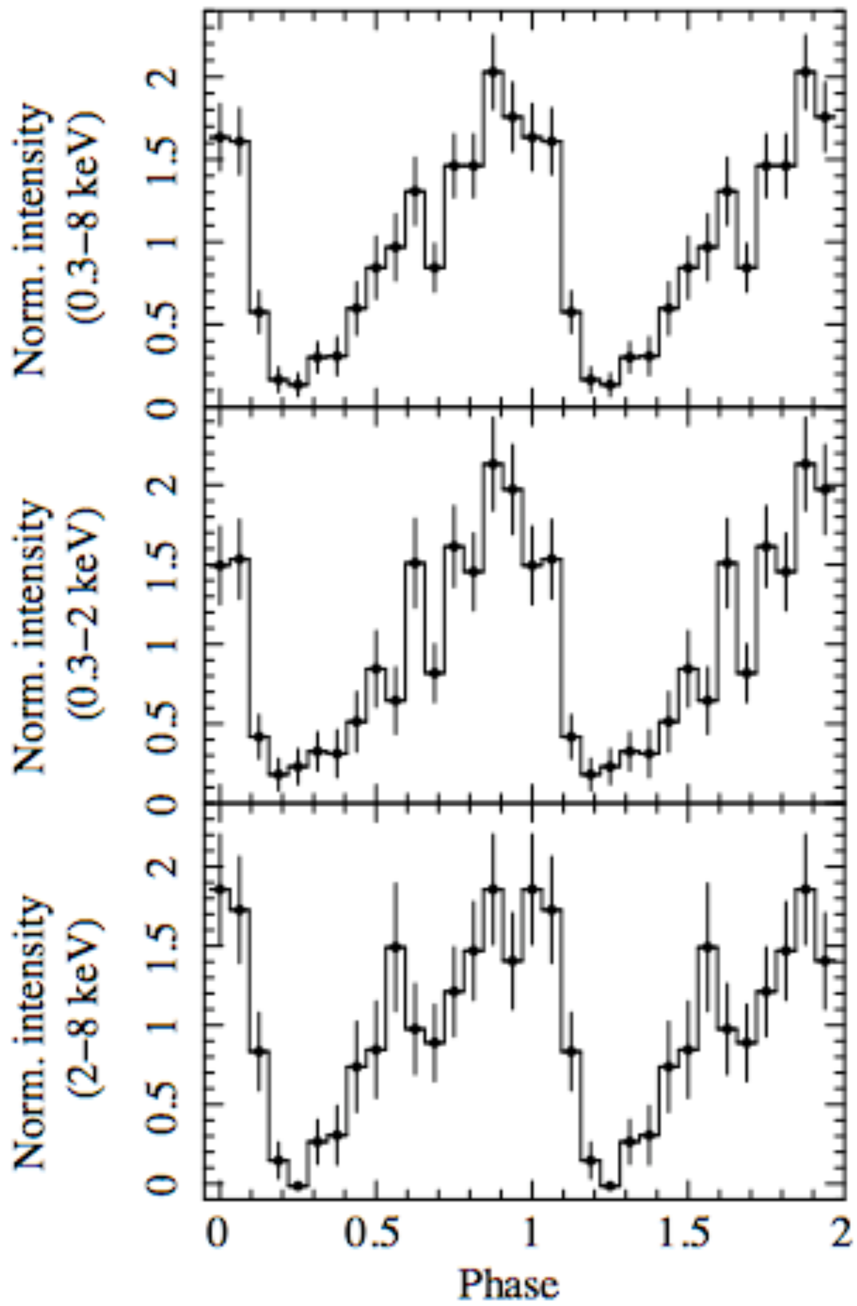
L from ~2×10^{38} to 1.1×10^{39} erg s^{-1}
(>2×10^{39} erg s^{-1} at the modulation peak)

BH binary

$L > L_E$ for a 5–10 $M_\odot$ object
(similar lower limit from the diskbb spectral fit)

LMXB: transients and with very different pulse profiles (even ADC sources)
UNLIKELY

HMXB? Possible, but only with a Wolf–Rayet companion…



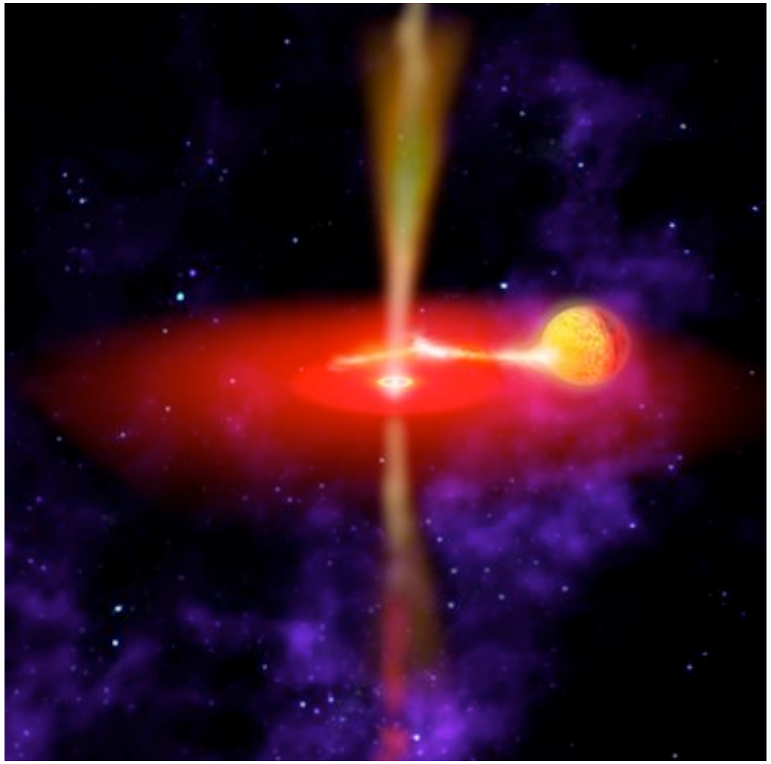
A peculiar system – 1

Only 3 other WR binaries are known:

Cyg X–3: WR + ?
a 2 $M_\odot$ NS or, more likely, a 3–5 $M_\odot$ BH
P = 4.8 h, L ~ 10^{38} erg s^{-1}
many similarities with the 6.4 h BHB

IC 10 X–1: WR + 33 $M_\odot$ BH
P = 34.9 h (Prestwich et al. 2007)

IC 10 X–1: WR + 20 $M_\odot$ BH
P = 32.3 h (Carpano et al. 2007)



NASA

Besides their rarity, WR/BH binaries are interesting because they might be progenitors of double-BH binaries

A peculiar system – 2

The NGC 4490 6.4 h BHB is a ‘part-time’, borderline ULX

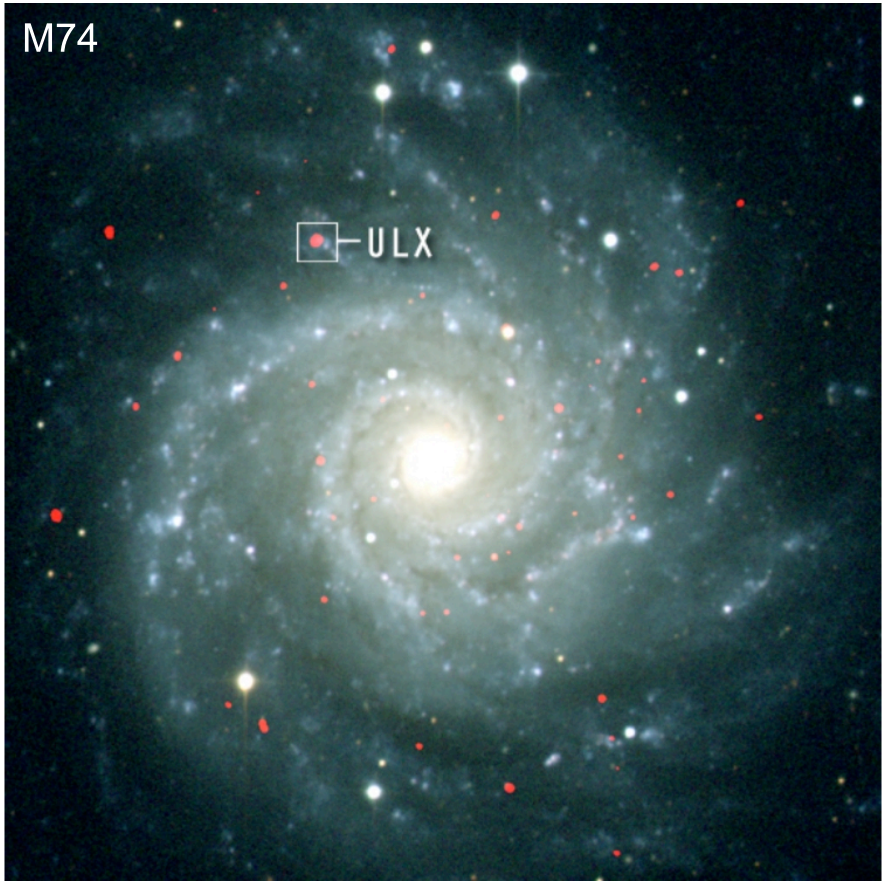
There’s a growing number of transient ULX with L_X at maximum slightly above 10^{39} erg s^{-1} (e.g. M31 ULX2, Esposito et al. 2013a, Middleton et al. 2012), some of them showing properties consistent with those of conventional BH binaries

The 9th ULX in NGC 4490/4485 (e.g. Fridriksson et al 2008)

The low metallicity of NGC 4490, $Z \approx 0.25\ Z_{\odot}$ (Pilyugin & Thuan 2007) supports the idea that ULXs tend to prefer metal-poor environments (e.g. Mapelli et al. 2010; Prestwich et al. 2013).

A possible interpretation is that the mass of BHs can be higher in metal-poor environments (e.g. Mapelli et al. 2013)

Ultra-Luminous X-ray Sources (ULXs)



NASA/CXC/U.Michigan/J.Liu et al./NOAO/AURA/NSF/T.Boroson

Non-nuclear point-like source with apparent X-ray luminosity $>10^{39}$ erg s^{-1} (which is the Eddington limit for spherical H accretion onto a 10-$M_\odot$ compact object)

≈500 known ULXs. Normal spiral galaxies typically contain just one or two such sources.

Taken off the known/ordinary objects (SNe, young INSs, foreground/background sources), we are left with accreting BHs

Ultra-Luminous X-ray Sources (ULXs)

Three main possible scenarios:

- **ordinary** stellar BHs (~5–20 $M_\odot$) emitting above their Eddington limit or with substantial beaming

- **"massive"** stellar BHs (~30–80 $M_\odot$) emitting at about their Eddington luminosity

- **intermediate-mass** BHs (~100–10,000 $M_\odot$) emitting below their Eddington luminosity

ULXs may well be a heterogeneous class

A few extreme ULXs (e.g. ESO 243-49 HLX-1, L_X~10^{42} erg s^{-1}; Farrel et al. 2009) are strong cases for IMBHs, but IMBHs are not needed to explain most of the data

A peculiar system – 2

The NGC 4490 6.4 h BHB is a ‘part-time’, borderline ULX

There’s a growing number of transient ULX with L_X at maximum slightly above 10^{39} erg s^{-1} (e.g. M31 ULX2, Esposito et al. 2013a, Middleton et al. 2012), some of them showing properties consistent with those of conventional BH binaries

The 9th ULX in NGC 4490/4485 (e.g. Fridriksson et al 2008)

The low metallicity of NGC 4490, $Z \approx 0.25\ Z_{\odot}$ (Pilyugin & Thuan 2007) supports the idea that ULXs tend to prefer metal-poor environments (e.g. Mapelli et al. 2010; Prestwich et al. 2013).

A possible interpretation is that the mass of BHs can be higher in metal-poor environments (e.g. Mapelli et al. 2013)

The Future

NGC 4490's 6.4 h BH binary

- Identification of the companion star
- Dynamical measurement of the BH mass
- New estimates of the metallicity of NGC 4490/85

CATS @ BAR

- Every 3/4 months we run the pipeline on the new ACIS data; new pulsators are coming
- Z^2-like algorithms, better suited for low-counts sources
- X-ray/optical follow-ups & classification

EXTRaS: an approved FP7 3-yr project (PI A. De Luca) that, among other things, will search the XMM EPIC archive for new X-ray pulsators, with sampling time of 6–73 ms

We need to name the XMM timing analysis …