The elusive nature of AX J0043-737

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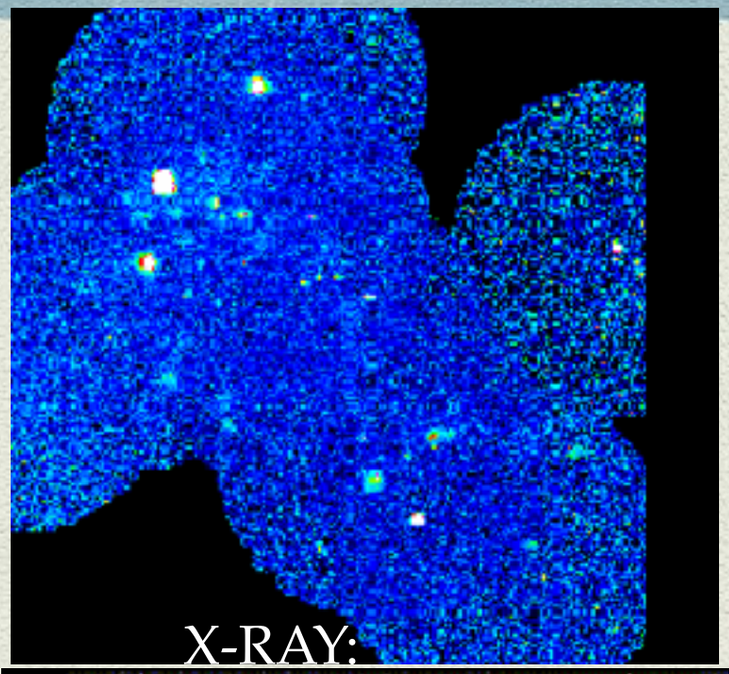
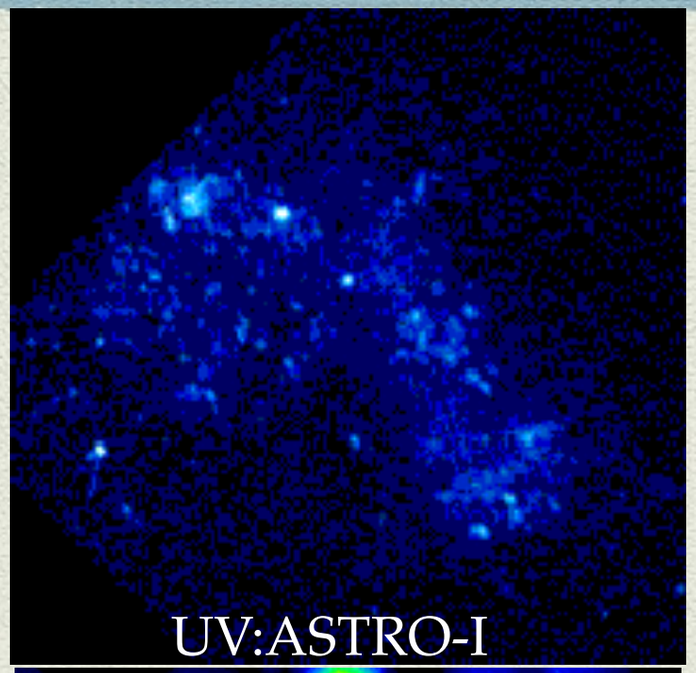
MODE-SNR-PWN workshop 2016

AX J0043-737

Small Magellanic Cloud: A rich astrophysical laboratory



X-RAY:



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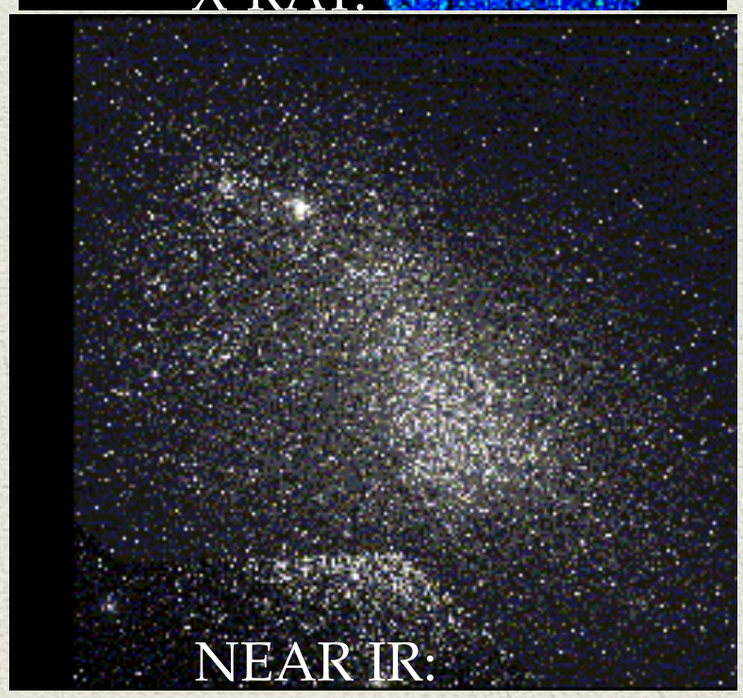
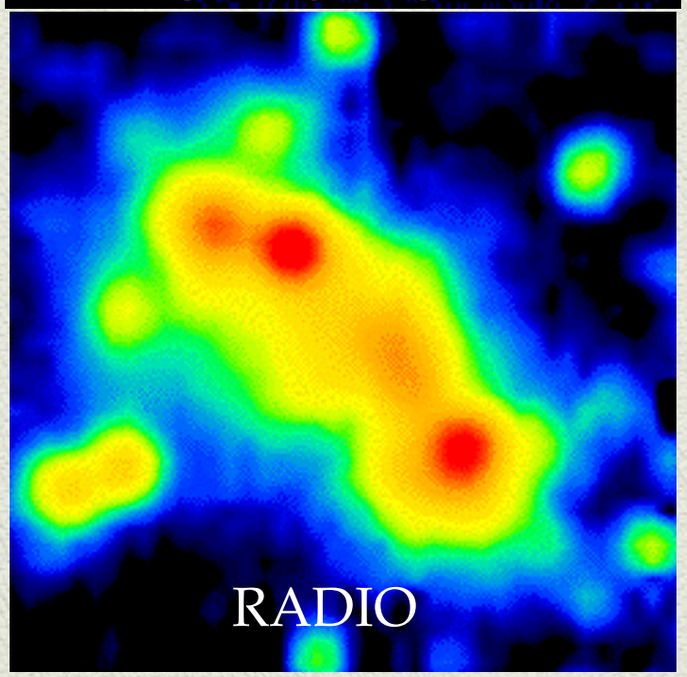


NEAR IR:



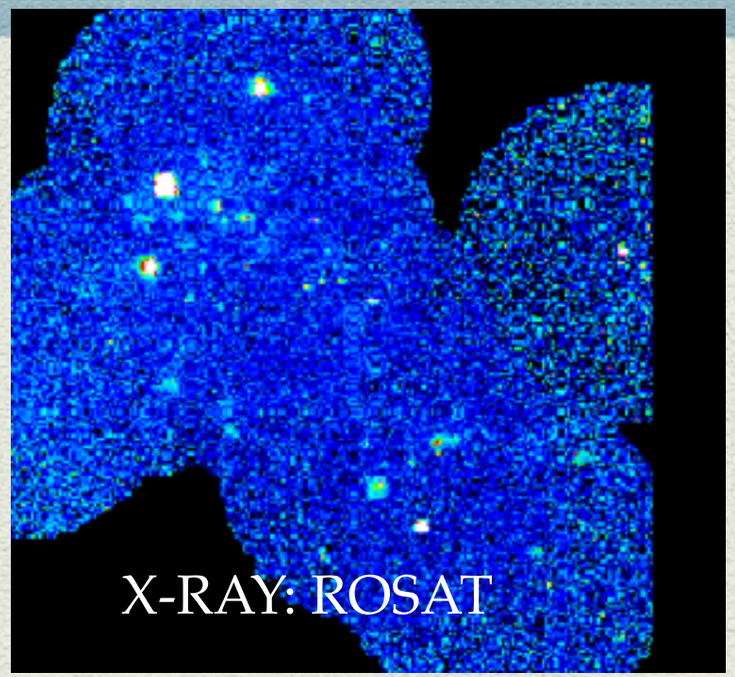
RADIO

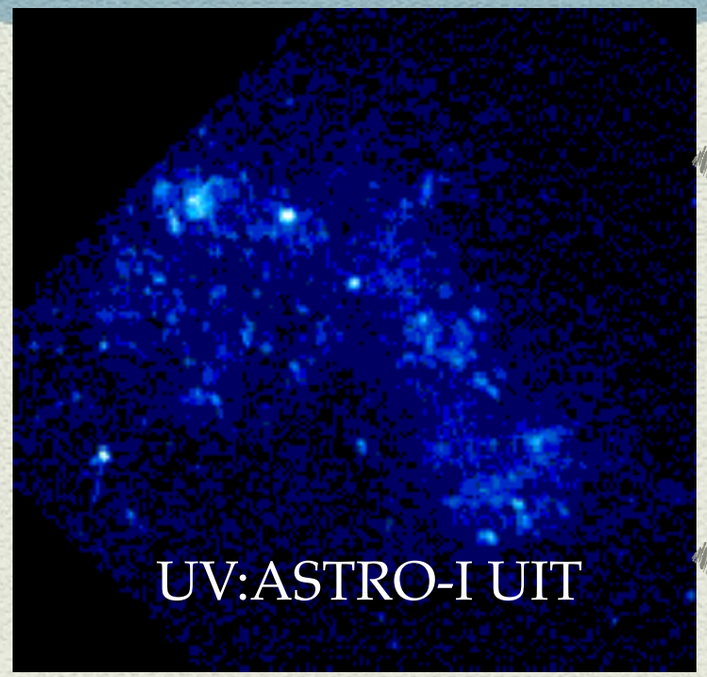
FIELD 3 X 3

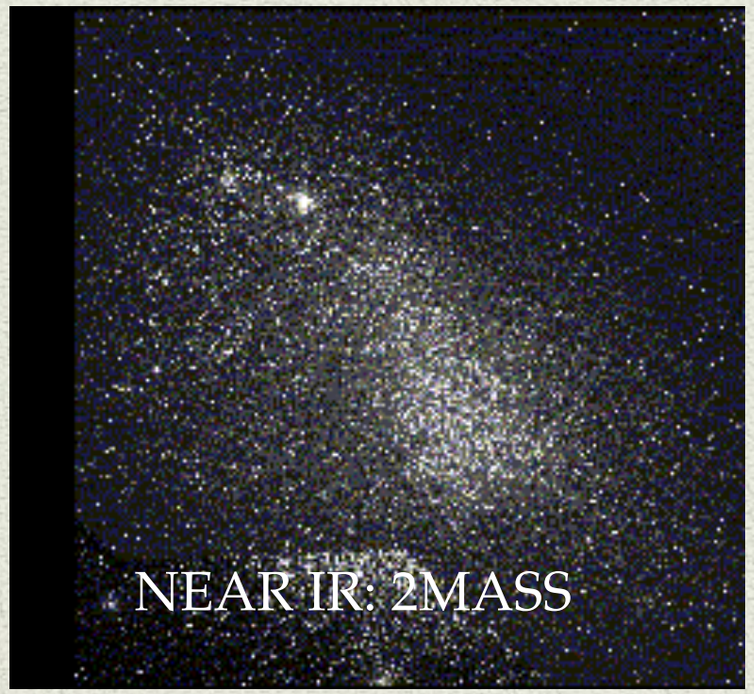
- Gas rich dwarf irregular Galaxy orbiting the Milky Way
- Second nearest star forming galaxy after LMC
- Low metallicity & strongly interacting

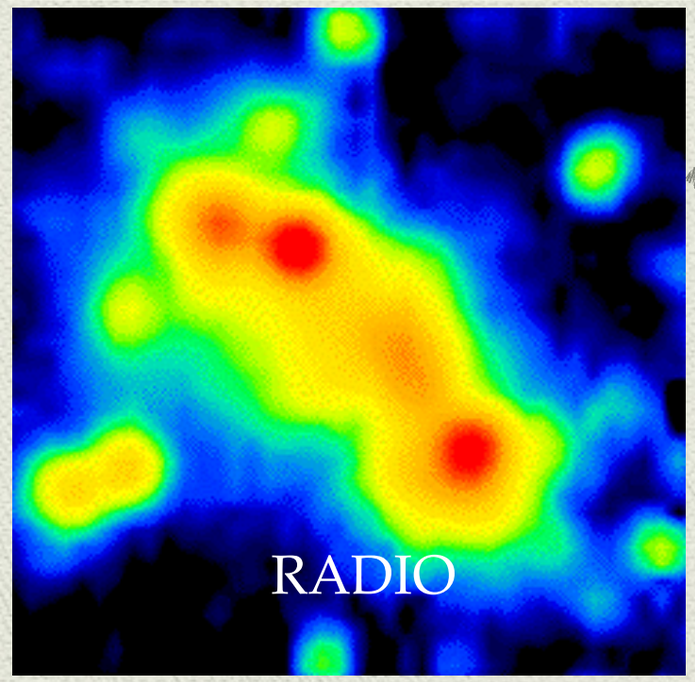
IMAGE:http://coolcosmos.ipac.caltech.edu/

Small Magellanic Cloud: A rich astrophysical laboratory


X-RAY: ROSAT


UV:ASTRO-I UIT


NEAR IR: 2MASS

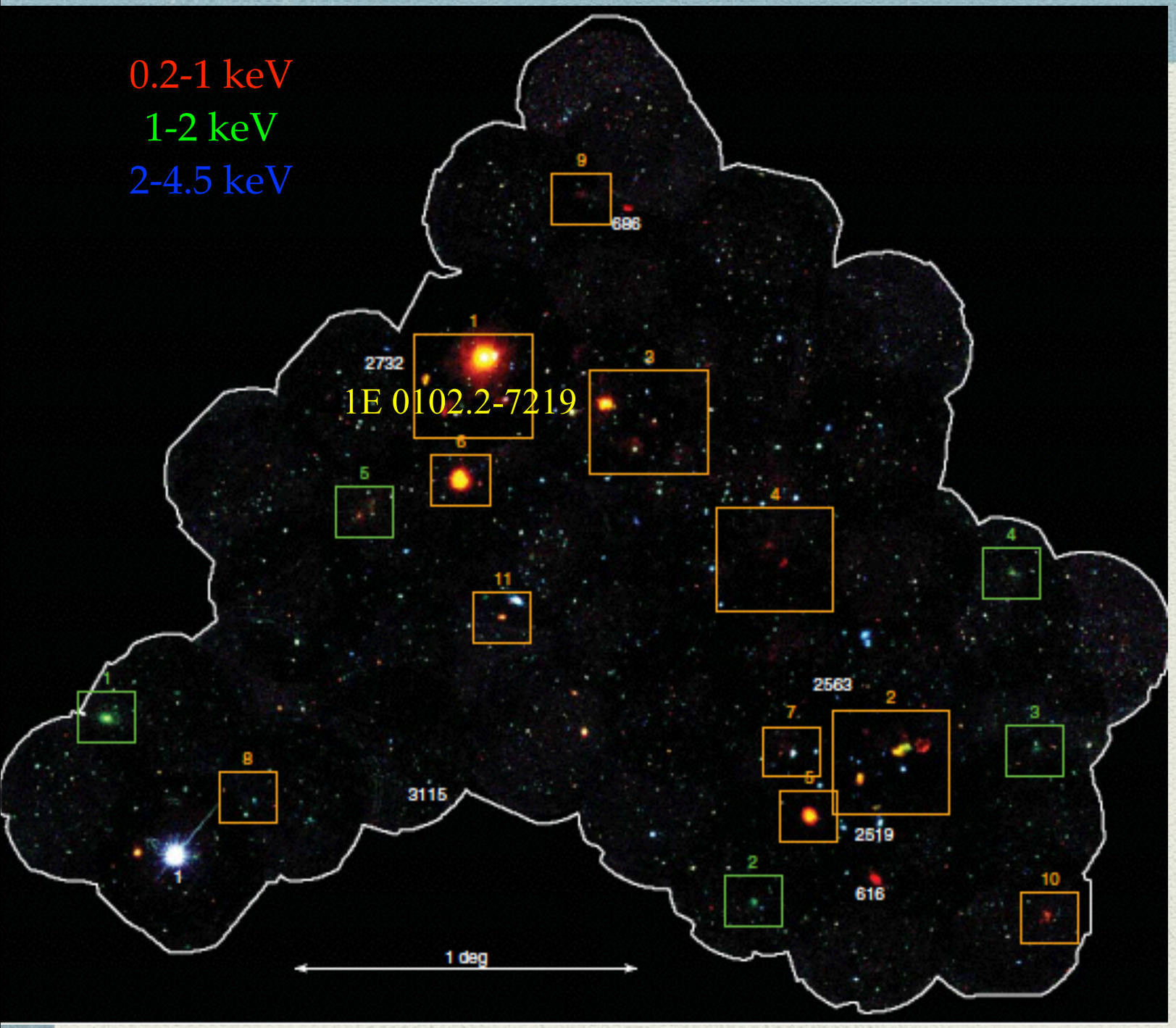

RADIO

FIELD 3 X 3 DEGREE

- Relative close distance and moderate Galactic foreground ~ 6×10^{20} cm^{-2}
- Limiting point source luminosity ~ 10^{33} erg s^{-1}
- Extended over large angular distance: requires instruments with large FOV and high spatial resolution

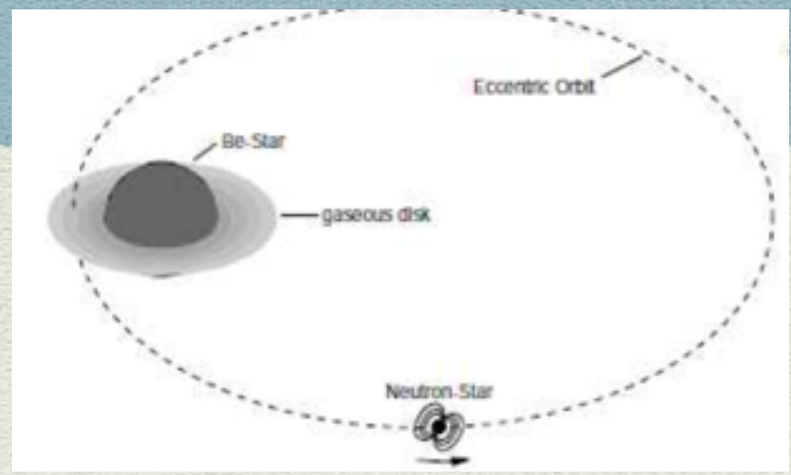
IMAGE:http://coolcosmos.ipac.caltech.edu/

XMM-NEWTON survey of the SMC: Haberl et al. 2012



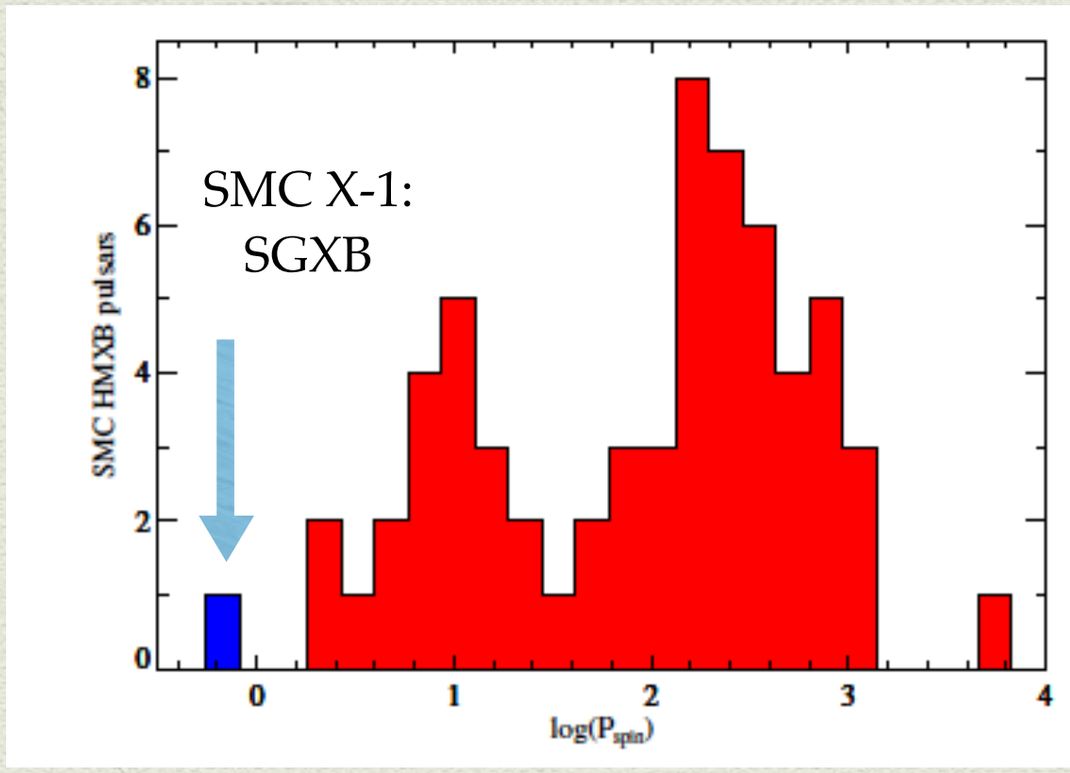
- 2009-2010: 30 fields + archive
- 5.6 deg^2 area in 0.2-12 kV
- 1 Ms exposure, sensitivity ~ 10^{-14} erg cm^{-2} s^{-1}
- Catalog of point sources: HMXBs & SSS (Sturm et al. 2013); SNRs & background Galaxy clusters (Haberl et al. 2012)

Ideal birthplace for X-ray pulsars: High star forming galaxy: Recent SF activity ~40 Myr ago



- Overabundant in Be X-ray binary pulsars (only 1 SGXB and one AXPs) (Sturm et a. 2013, Haberl & Sturm 2015)

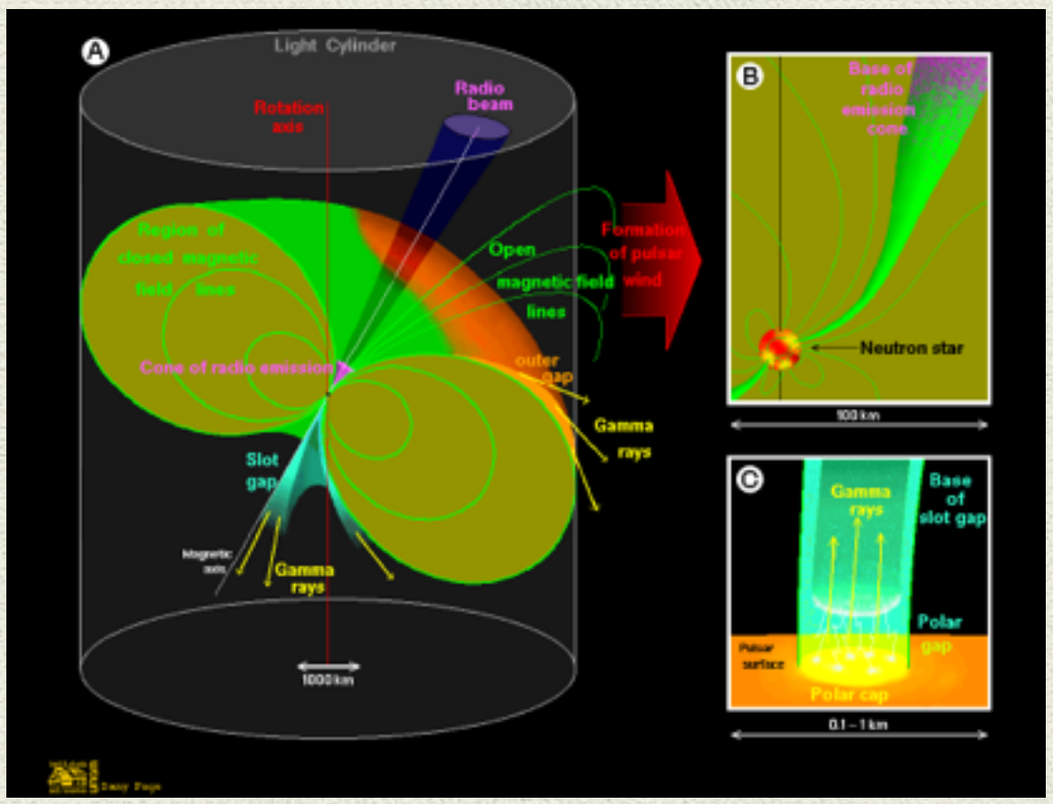
- Many unique BeXrBs. Population ~ 10^6 yr, spin distribution 1-1000 s (Bimodal) (Haberl et al. 2008)



Spin period distribution of 63 HMXB pulsars :(Haberl & Sturm 2015)

This is only half the story of SMC pulsars.

what about the younger population, the Rotation Powered Pulsars (RPPs)?



http://www.astroscu.unam.mx/neutrones/NS-Picture/MagSphe/MagSphe.html

- Source of emission E_{rot}, pulsar's rotational energy.
- Rate at which dissipated $E_{dot} = -dE_{rot}/dt$

Target: Young RPPs

age < 20 kyr; Period < 100 ms, $E_{dot} > 10^{36}$ erg s^{-1}

- Parkes Multibeam radio survey in the Magellanic clouds (Crawford 2001, Manchester 2006); Updated High resolution survey (Ridley et al. 2013) found new RPPs

- Total RPPs 23 in LMC, 5 in SMC

- Current Census: LMC 3 systems < 100 ms, J0537-6910 Crab like 16 ms pulsar with highest E_{dot}, SMC = 0

Expected Observable Population in SMC (Ridley & Lorimer 2010):

Expected birth rate 0.5-1 pulsar/century. > 150 pulsars with age < 20 Kyr expected.
Considering beaming & other effects ~ 15 such systems

Observed: Milky Way ~ 30 young RPPs, LMC ~3 ; SMC ??

Missing younger counterparts? Search in X-rays?

Recent evidence in X-rays of the first PWN in the SMC IKT 16 (Maitra et al. 2015)

AX J0043-737: The elusive source in ASCA catalog

AX J0043-737 (IAU Circ , 2000, 7361)

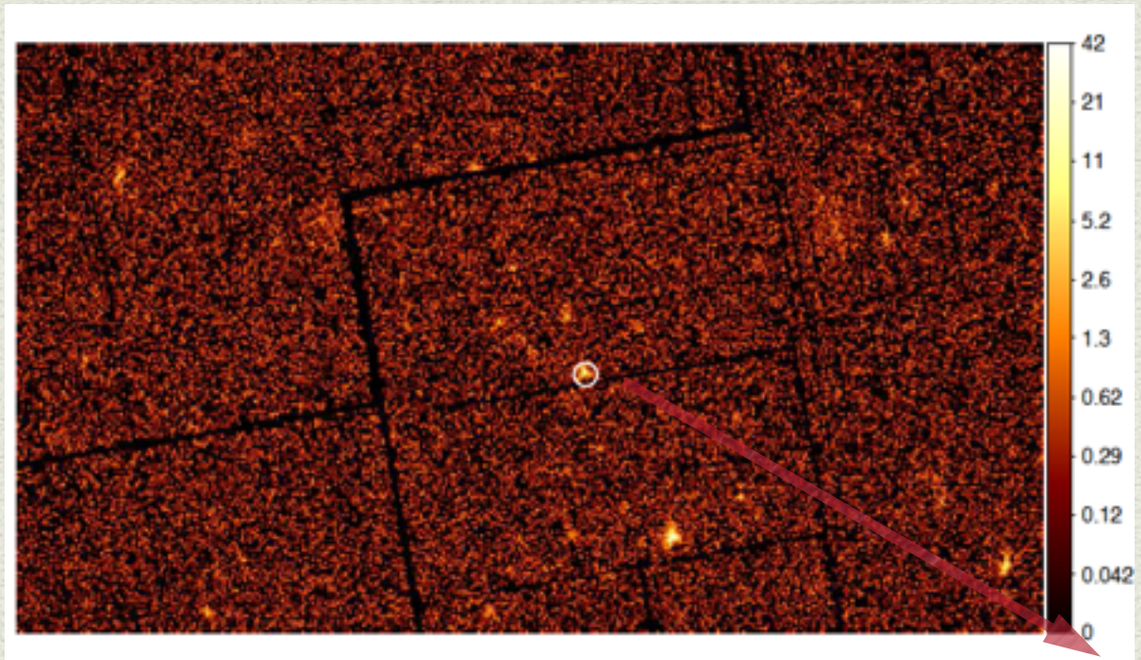
J. Yokogawa and K. Koyama, Kyoto University, write:

"An ASCA observation of the Small Magellanic Cloud (SMC) on 1999 May 10-11
detected coherent pulsations of period **87.58073 +/- 0.00004** ms with a significance of **99.98** percent from AX J0043-737, which is located at R.A. = **0h42m35s,** Decl. = **-73o40'30"** (equinox 2000.0; +/- 1' at 90-percent confidence). The spectrum was described by a power law with photon index **1.7 (+0.9,-0.5).** The x-ray flux in the band 0.7-10.0 keV was 2.0 x 10**-13 erg s**-1 cm**-2, corresponding to a luminosity of **8.6 x 10**34 erg**/s for a distance of 60 kpc. We suggest that AX J0043-737 is a Crab-like pulsar in the SMC, although the possibility of an x-ray binary with a short pulse period is not excluded. Within the ASCA error region, a ROSAT source RX J0042.6-7340 is found (Kahabka et al. 1999, A.Ap. Suppl. 136, 81). Confirmation attempts at x-ray, radio, and other wavelengths are encouraged."

Fastest pulsar in SMC ? A little more than 3 σ detection !

- Reported by Yogokawa 2003 in SMC point source catalog as fastest pulsar!
- Not confirmed in the second ASCA observation
- Still quoted likewise. Requires urgent followup

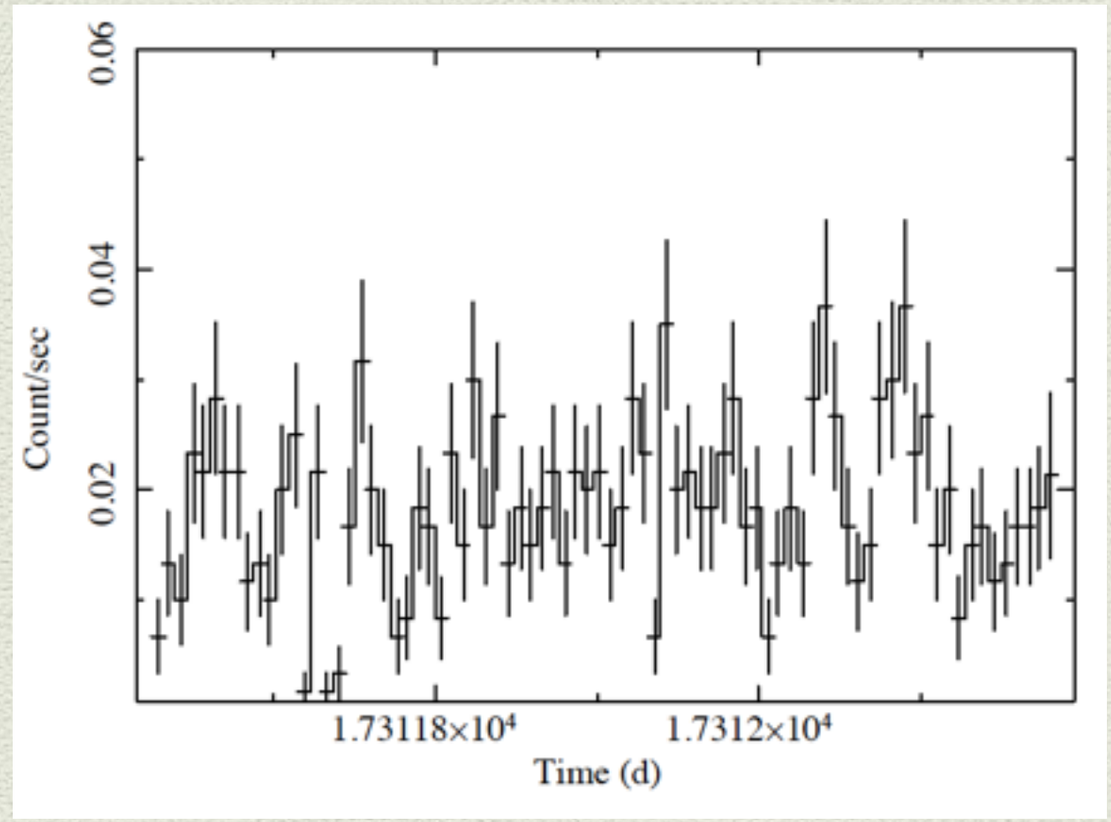
On axis XMM-Newton observation 40 ks
October, 2015: XMM AO14

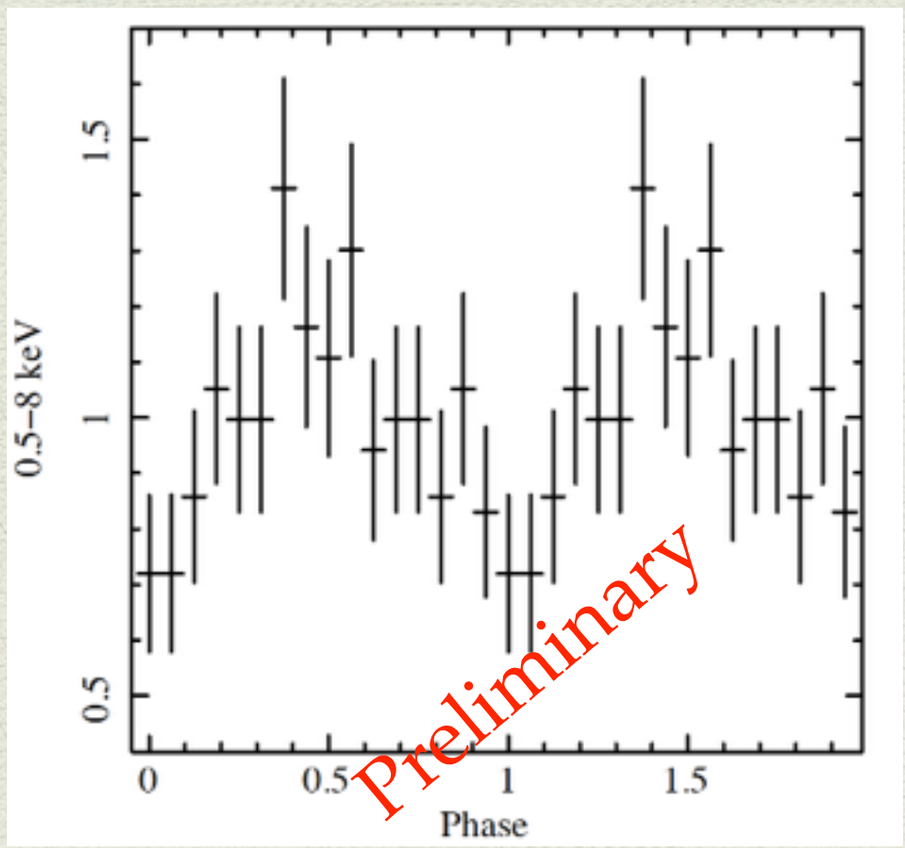


AX J0043-737

- PN in small window mode (SW); time resolution 5.7 ms, higher effective area (0.2-12 keV)
- Improved position of the source
- Confirm or refute the pulsation
- Measure $\dot{P}$ if detected
- Accurate Measurement of spectrum

Search for Pulsed signal in PN data

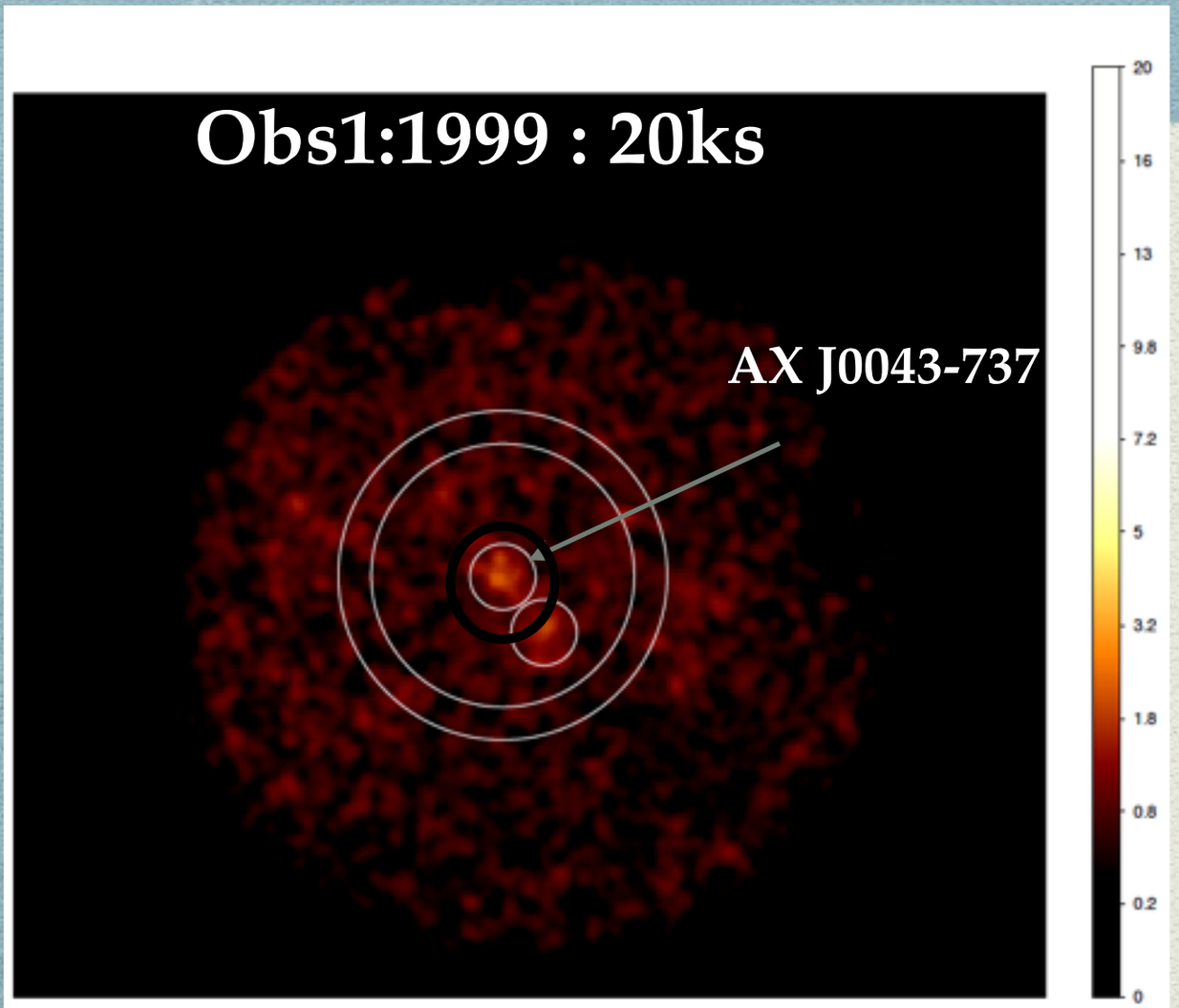


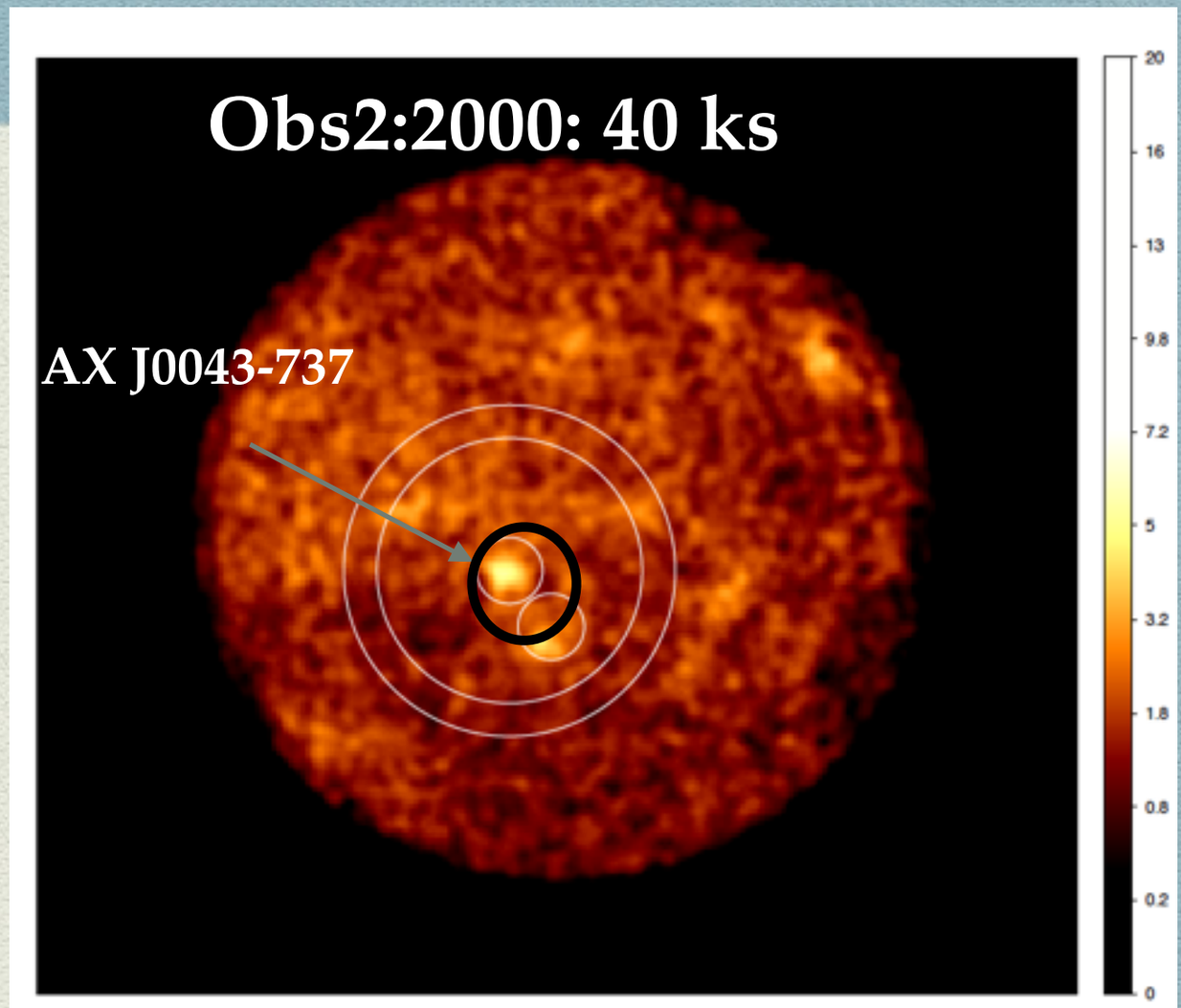


- Searched for periodic signal by Z^2 n (Rayleigh) test and epoch folding technique

- P=87.53023(3) ms ; significance ~ 4.9 σ (single trial P=8.06e-7)
- Uncertainty to be estimated carefully to quantify $\dot{P}$

A look back at the old ASCA data: 1999 & 2000 observations

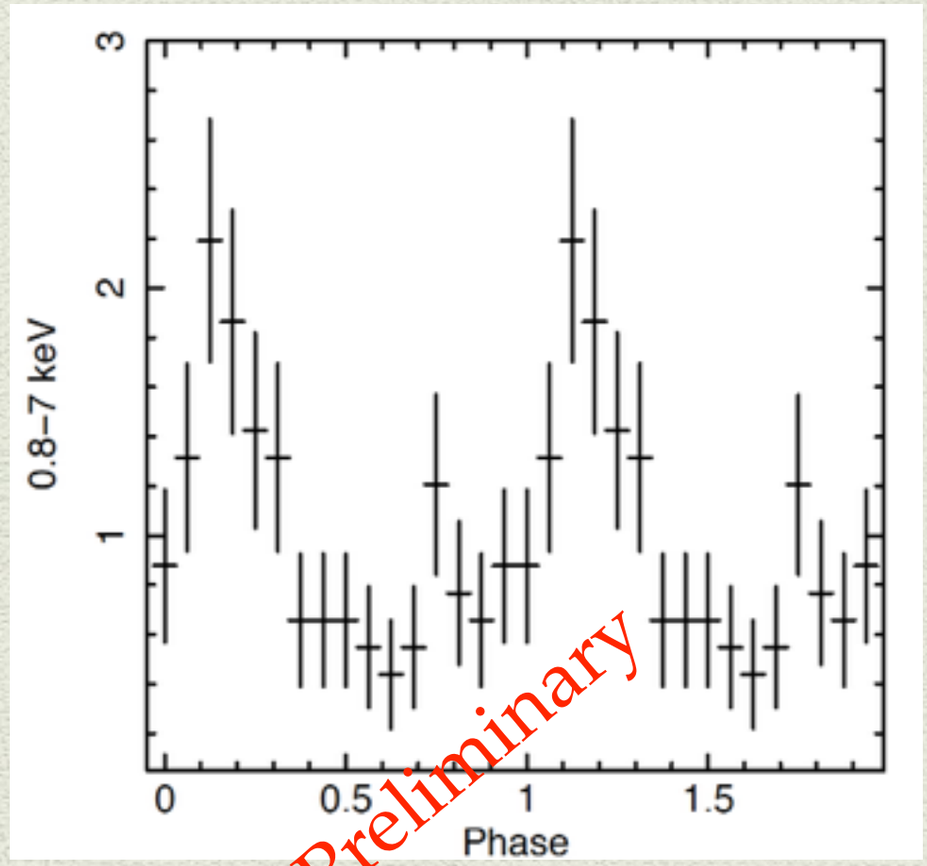




- GIS in Pulse Height mode (Fast & Medium bit); time resolution 31.25 ms, (0.7-10 keV)
- Contamination from a candidate HMXB in the prescribed ASCA extraction circle
- Look for pulsation signature around the same period in the data

A look back at the old ASCA data: 1999 & 2000 observations

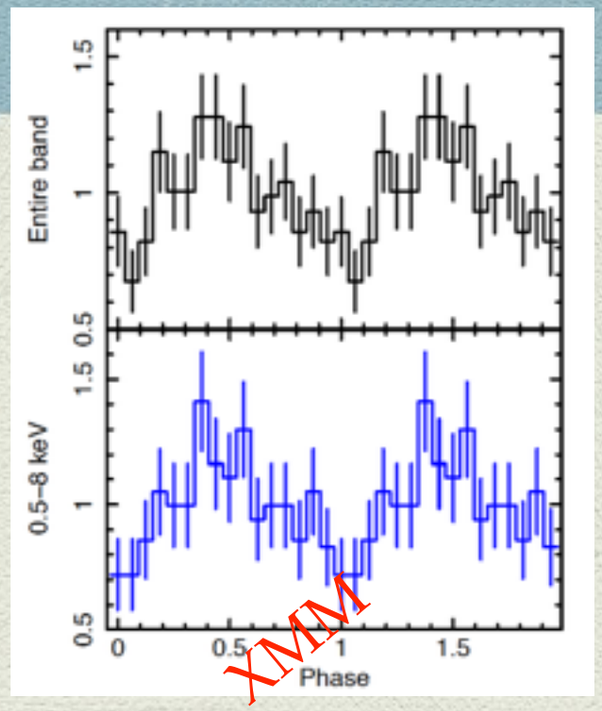
1st ASCA Observation

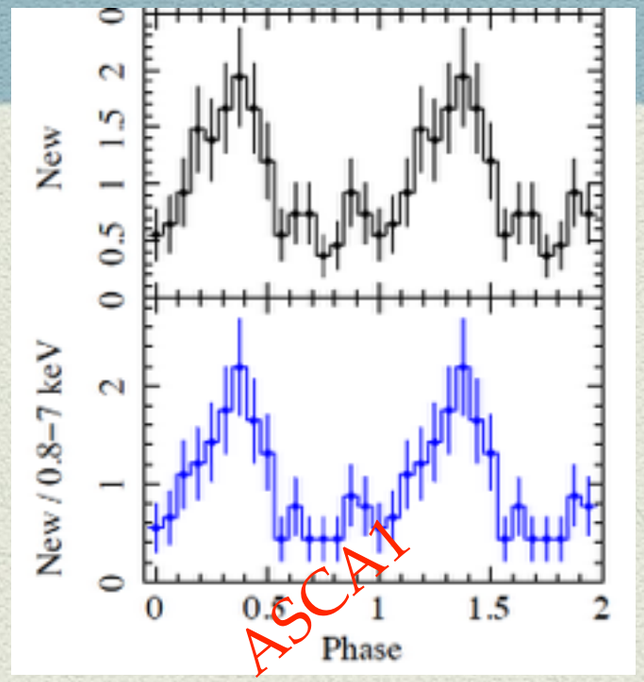


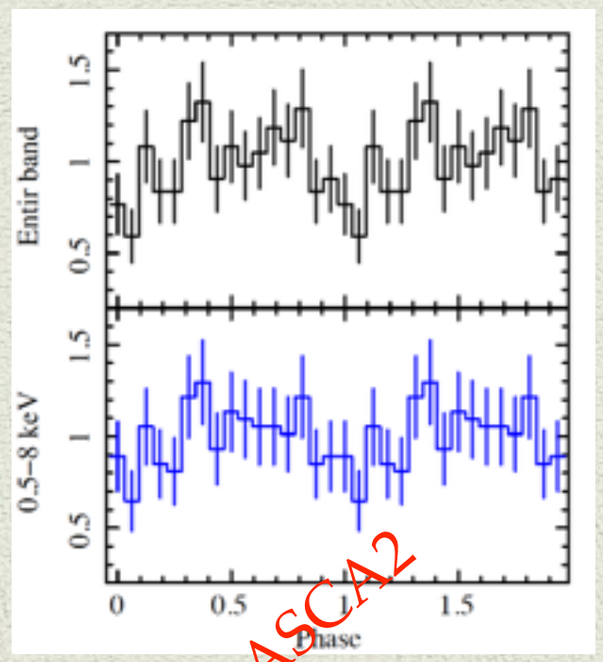
2nd ASCA Observation

- Peak found at 87.580733(2) ms for Obs1 (same as Yogokawa) but not at same significance..

Timing results at a glance..





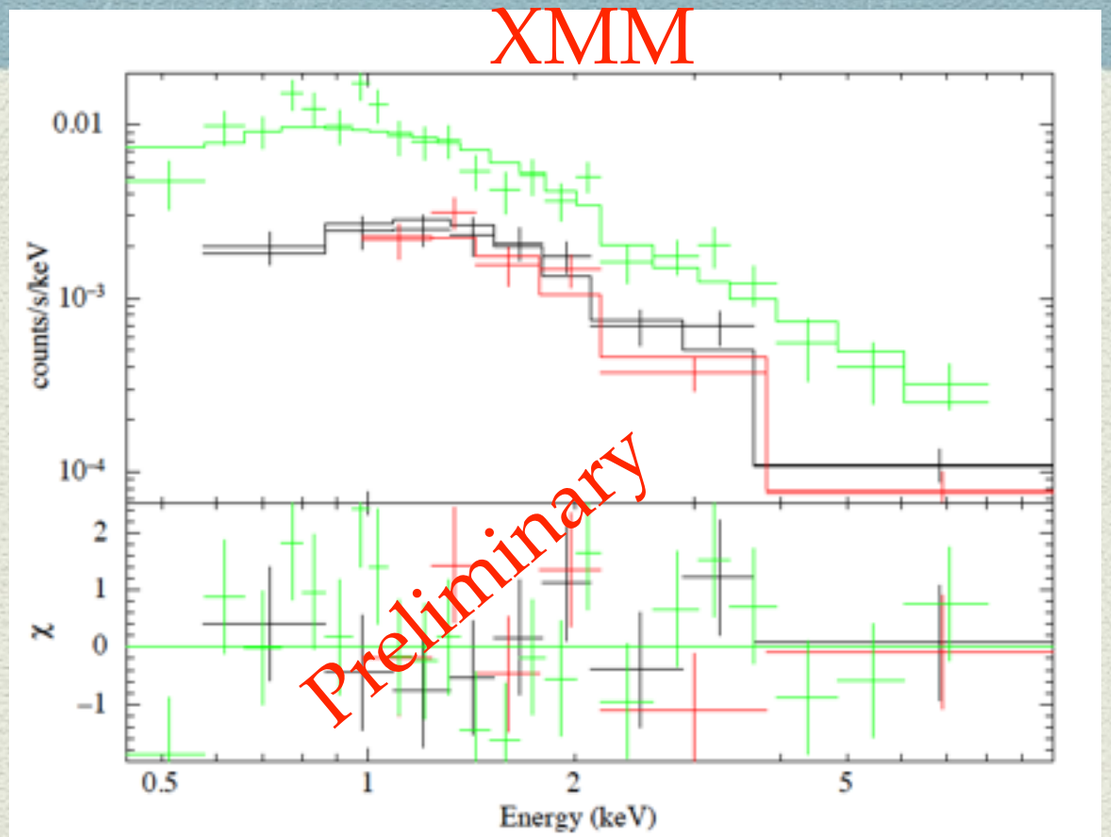


observation	Pulse period (s)	Pulse fraction (%)
XMM (2015)	**0.08753023**	**56%**
ASCA2 (2000)	**0.08755187**	**32% (upper limit)**
ASCA1 (1999)	**0.08758073**	**60%**

- periodicities in ASCA observation needs to be refined with more sensitive tests
- Signature of spin up with time (?)

Spectrum of AX J0043-737

XMM

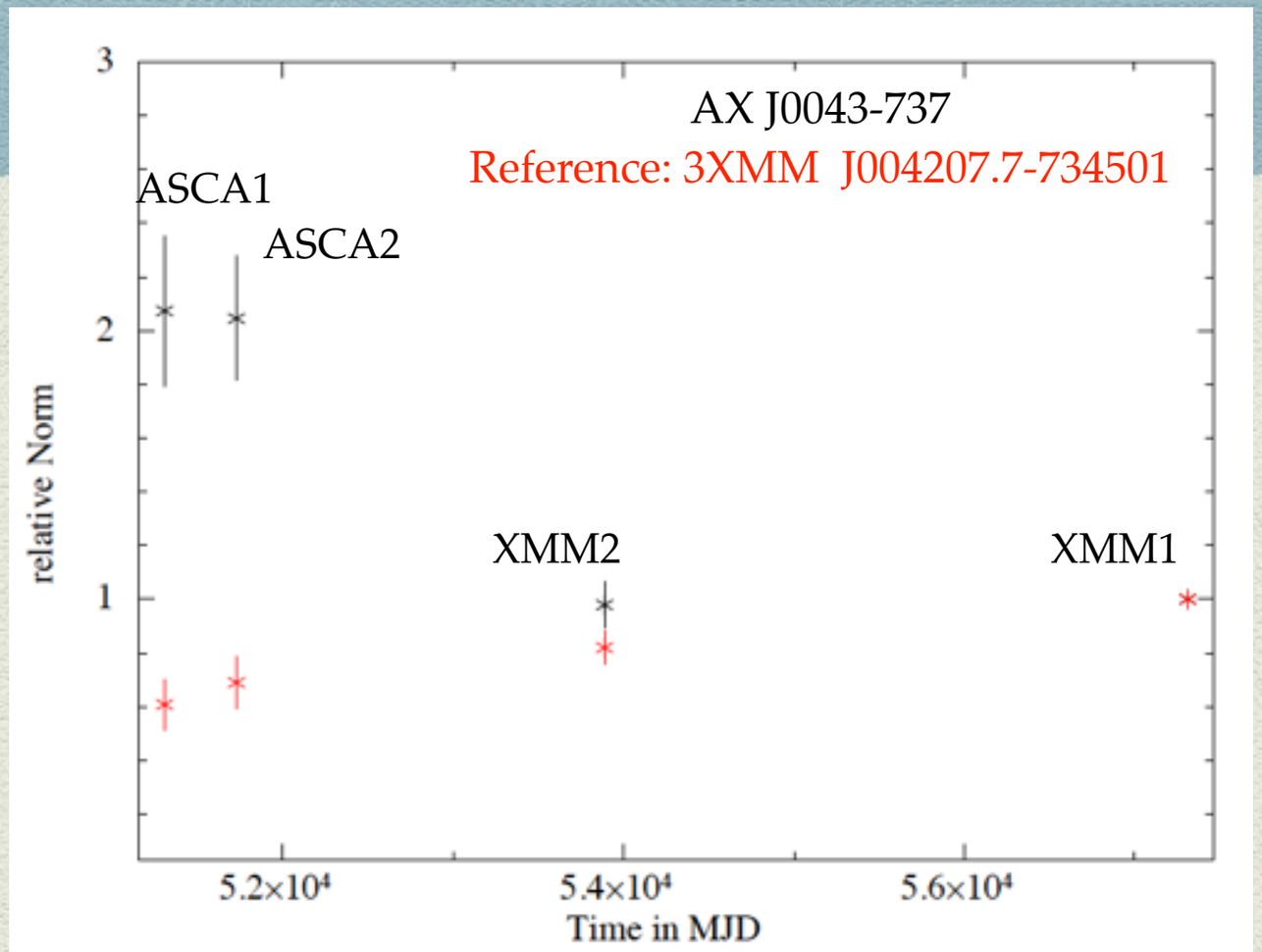


Spectral shape consistent with an absorbed powerlaw of $\Gamma \approx 1.6 \pm 0.1$.
No evidence of local absorption
Lx (0.7-10 keV) ~ 3×10^{34} erg/s

Comparison with other SMC pulsars (Haberl & Pietsch 2003; Haberl et al. 2015)

- Spectral index softer then other SMC pulsars ($0.65 \lesssim \Gamma \lesssim 1.45$) .. but all are Be-binaries
- Low luminosity & low absorption consistent with most other systems

Spectral variability in AX J0043-737 ?



Observation	Exposure (ks)
XMM1 2015	**40**
XMM2 2006	**15**
ASCA2 2000	**20**
ASCA1 1999	**60**

- Two sources fitted simultaneously for all observations taking into account % of contamination of one source region into another
- Performed with N_H & Γ tied for each source . Relative normalizations between observations free
- $\Delta X^2 = 40$ for 3 do.f between leaving the normalizations free and tying them to 1
- Evidence of variability over long timescales. Flux decreased ?

Search for radio & optical counterpart at XMM position

- No radio source at XMM position
- Previous studies cataloged the source as a background AGN (Sturm et al. 2013)
- Optical counterpart searched with refined XMM position with 1 " (90 % confidence error circle for the source is 0.9")
- Three optical sources within XMM error circle

Criteria for X-ray pulsars in SMC (Coe et al. 2005)
Spectral type B0V-B2V
V ≤ 17.0
-0.2 < (B-V) < 0.2

Distance	B	V	B-V	Source
0.83"	-	23.28	-	Quasars catalog
0.84"	22.04	21.96	0.08	magellanic cloud photometric survey
1.1"	20.21	19.49	0.7	magellanic cloud photometric survey

- No B star at the position. Possibly also coincident with a background AGN

Summary

Evidence for pulsar

- Periodicity detected in the XMM data at the same period as reported from ASCA; significance 4.9 σ (Need to confirm the ASCA periodicity)
- Comparable pulse fraction between XMM and ASCA observation1
- Absorbed powerlaw with $\Gamma \sim 1.6$ consistent with a pulsar

Not an isolated pulsar

- Evidence of spin up $\dot{P} \sim 10^{-14}$
- Evidence for long term flux decrease with time

Not a Be X-ray binary pulsar

- No B star at the source position
-

Ongoing work: tying up loose ends!

- Need to increase the significance: in order to detect sensitivity of pulsed signal '**Weighted Z^2 test**' (Kerr 2011)
- Quantify $\dot{P}$
- Perform follow-up optical photometry and spectroscopy at source position
- Dedicated radio search at the source position

STAY TUNED

THANK YOU