Young non-recycled X-ray pulsar in one of the Universe's **oldest** stellar systems

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The story

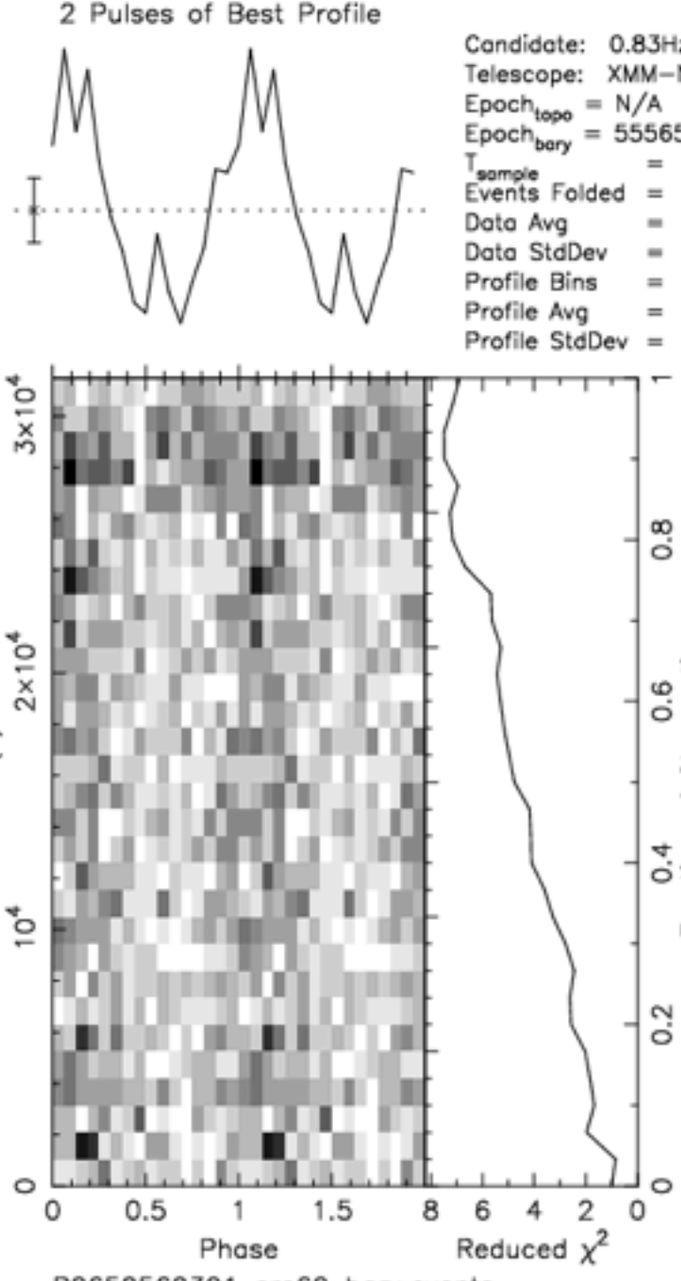
- Bachetti et al., *Nature* (2014) – extragalactic super-Eddington pulsar in M82
- Motivation: check if there are other pulsating ULX
- Clear pathway: take all ~600 ULXs and see if there are pulsations

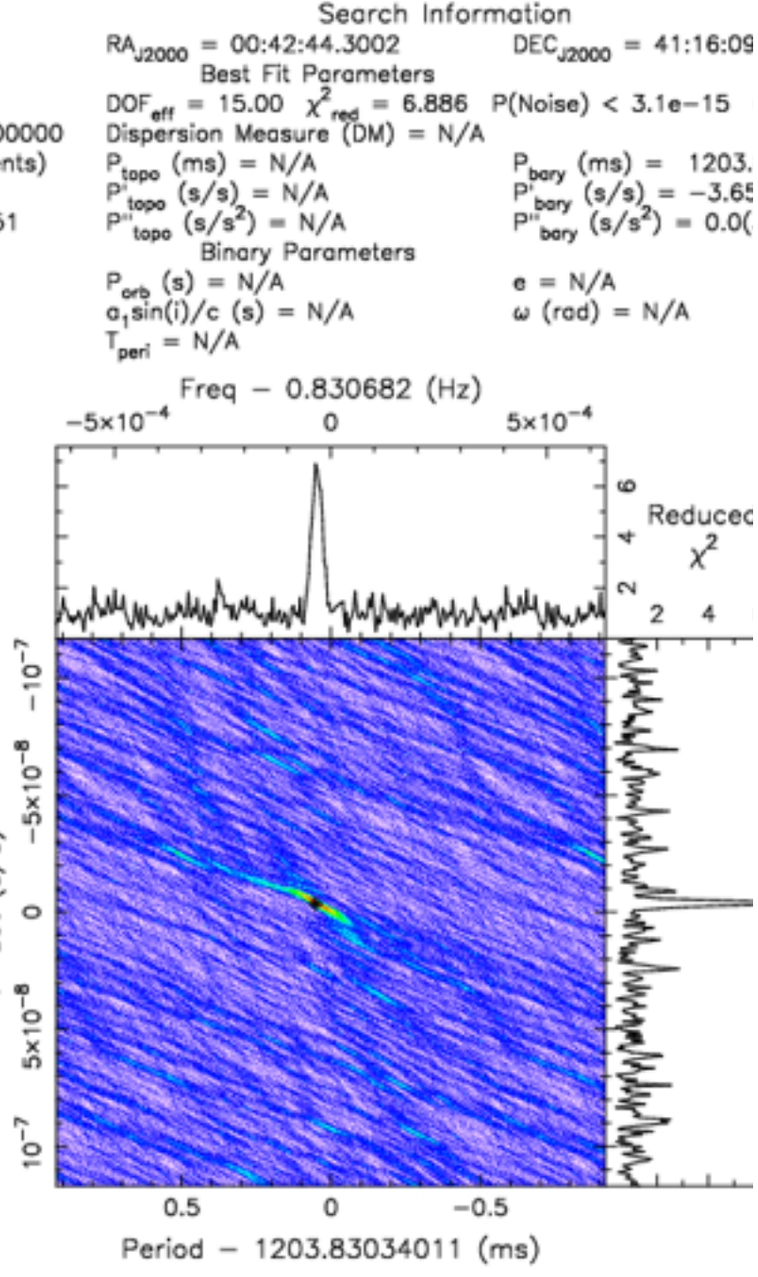
The *XMM-Newton* photon database

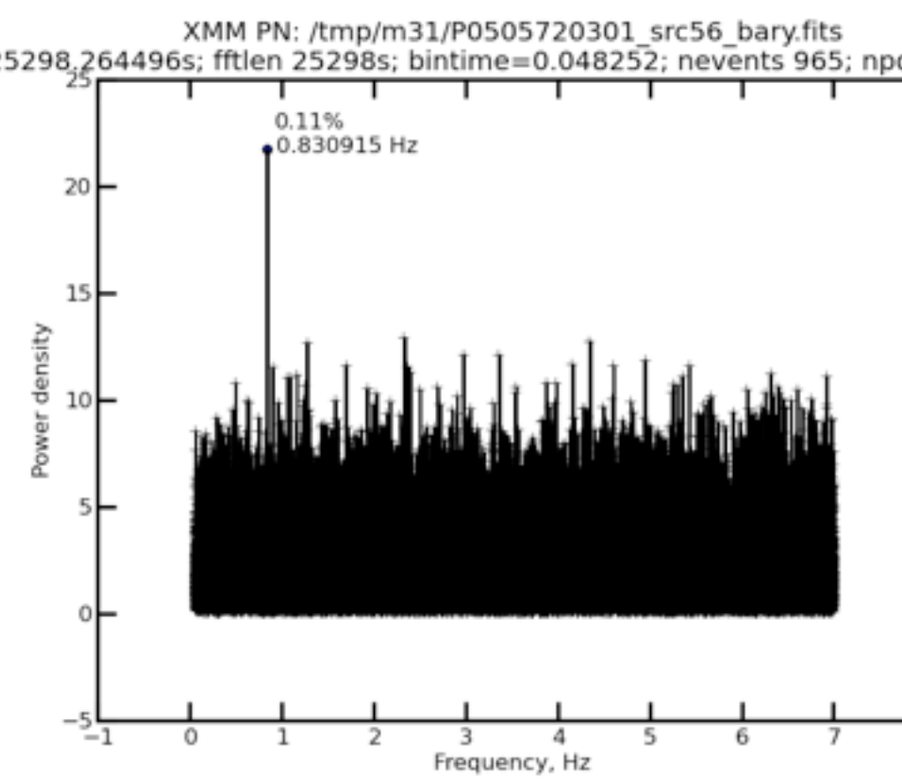
- 7300 observations of 3XMM-DR5
- Filtered and calibrated event lists (PIEVLI) produced by the XMM SSC and publicly available from ESA Archive
- ~50 billion photons
- Automated barycentering
- Everything is on the web: http://xmm-catalog.irap.omp.eu

Pulsar factory

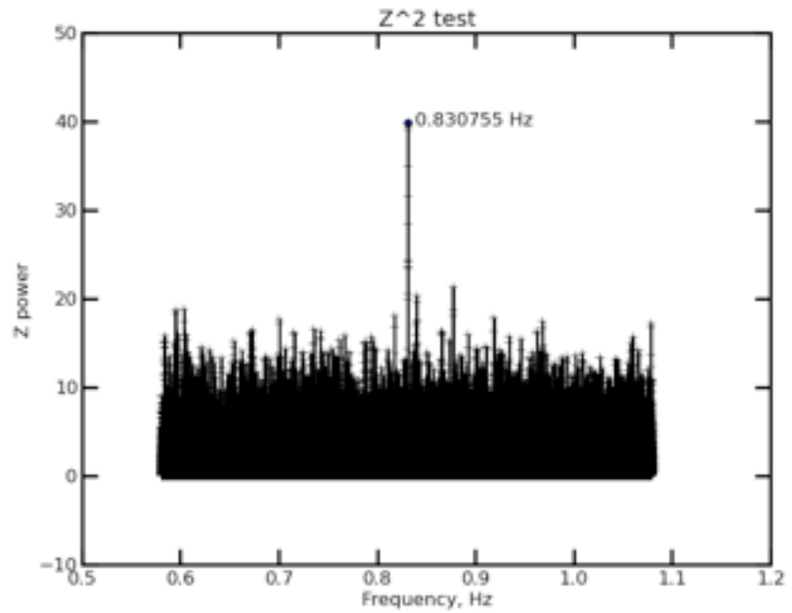
- Pipeline that searches for coherent pulsations by RA-Dec coordinates or 3XMM-DR5 source
- PDS of small data chunks → Z^2 test → PRESTO
- Andromeda galaxy as test sample (9k detections)

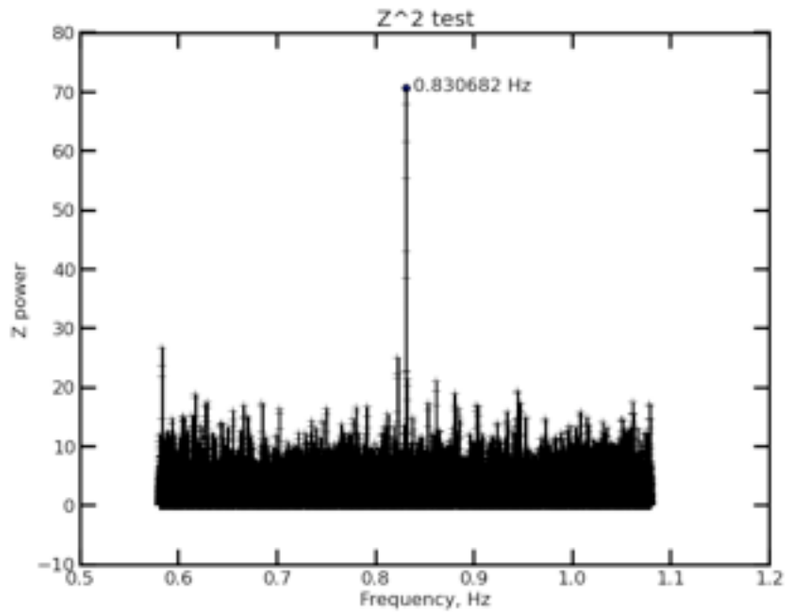






P0650560301_src60_bary.events

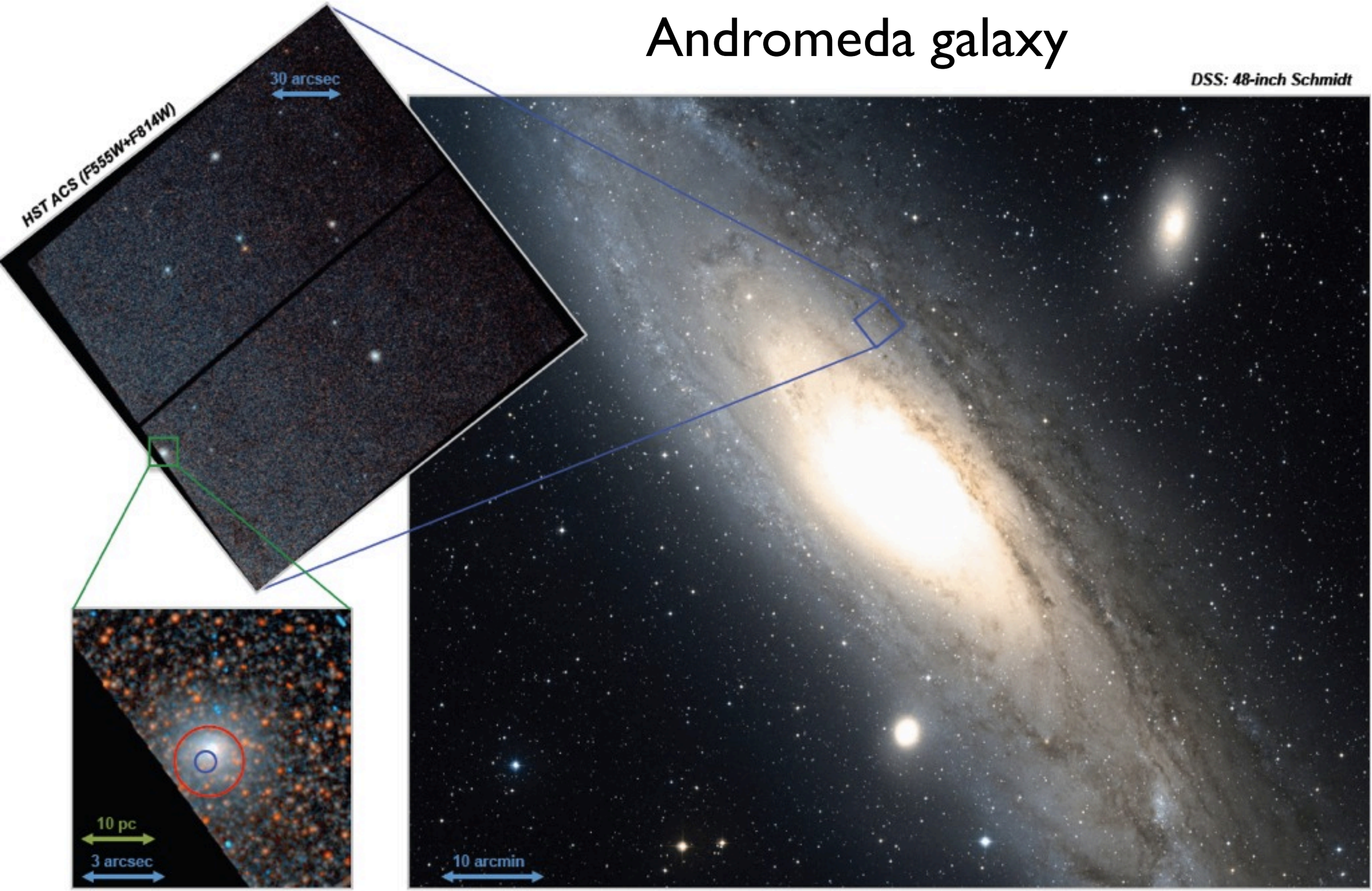




Nov 29, 2014

Now even online!

Globular cluster B091D in Andromeda galaxy



Pulsar recycling concept

- NS is born quickly rotating
- Then slows down in rotation-powered phase (radio pulsar)
- Millisecond pulsars with P_{spin} ~ 1-10 ms and B ~ 10^8 G dominate in GCs
- They were in accreting binaries
- Accretion buries magnetic field
- and spins up the neutron star

Pulsar

- L_X = (3...10) x 10^{37} erg/s
- Spin period: 1.20 seconds
- Orbital period: 109.8 ksec = 30.5 hours
- In a globular cluster B091D: chance superposition probability ~10^{-3}
- Hence nickname: XB091D
- Closest known analog: "mildly-recycled" pulsar IGR J17480-2446 in Terzan 5

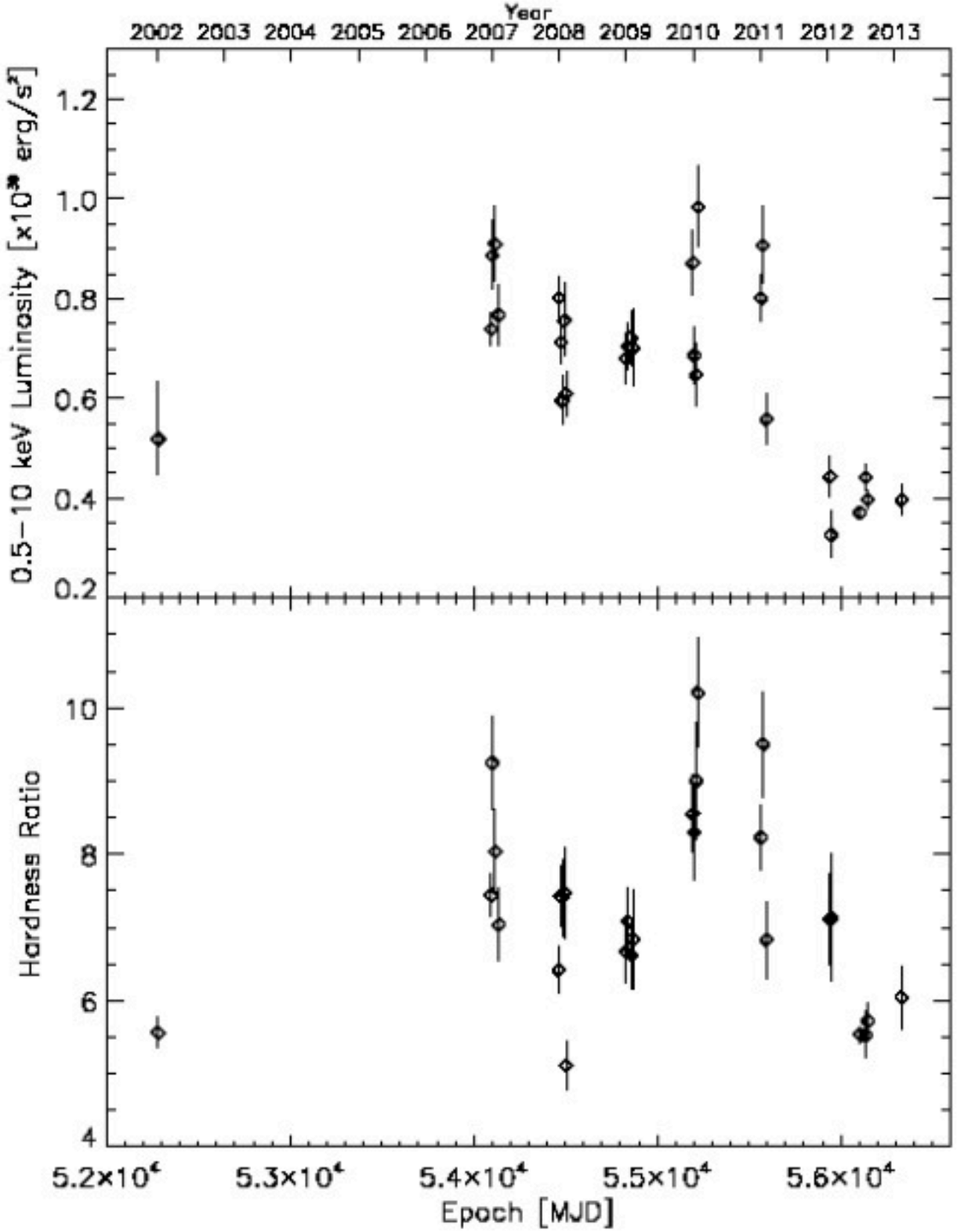
IGR J17480-2446

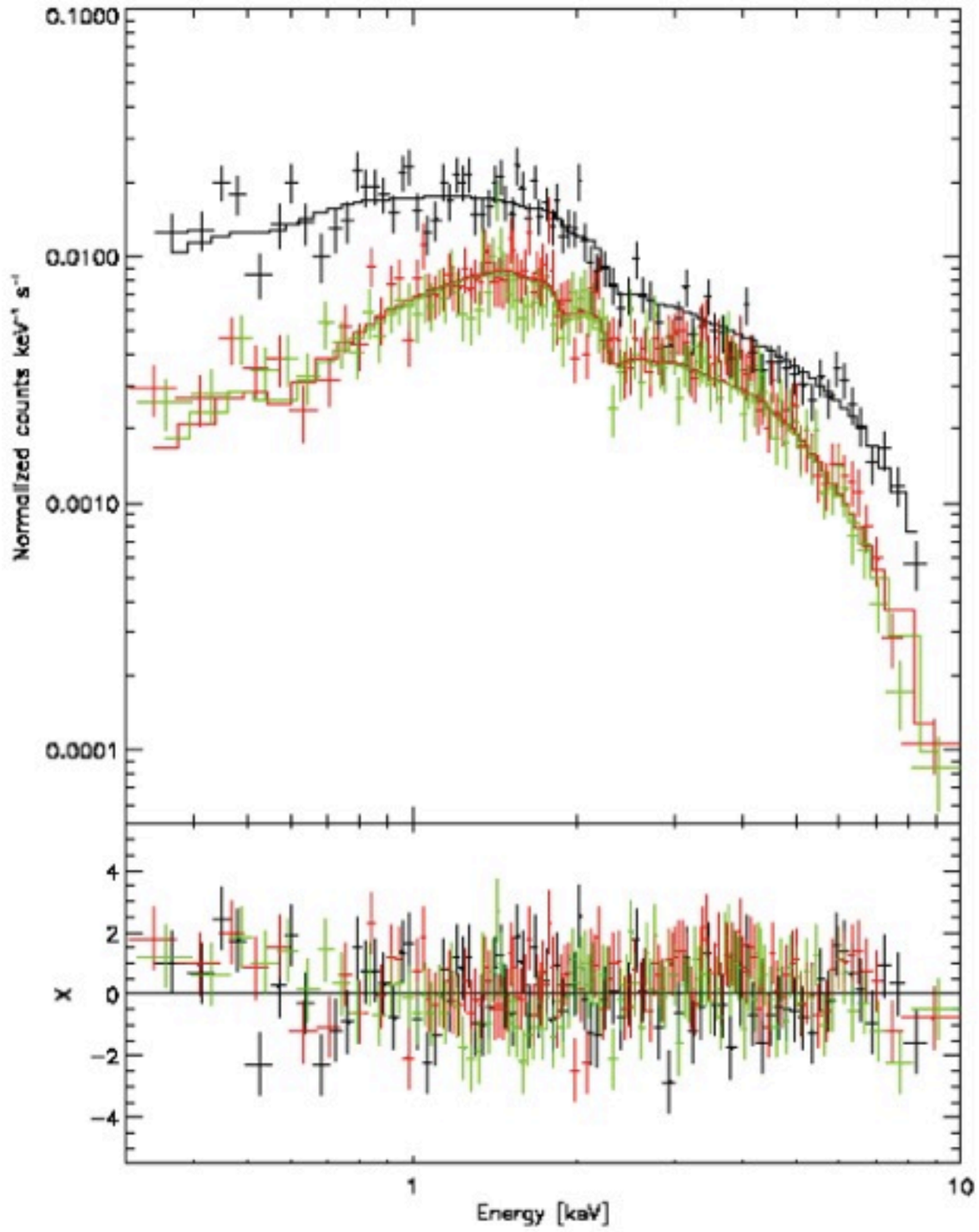
- L_X = 2...7 x 10^{37} erg/s
- P_{spin} = 0.09 s
- P_{orb} = 21.3 h
- Mildly-recycled
- Host: Terzan 5

XB091D

- L_X = 3...10 x 10^{37} erg/s
- P_{spin} = 1.20 s
- P_{orb} = 30.5 h
- Non-recycled
- Host: M31 B091D

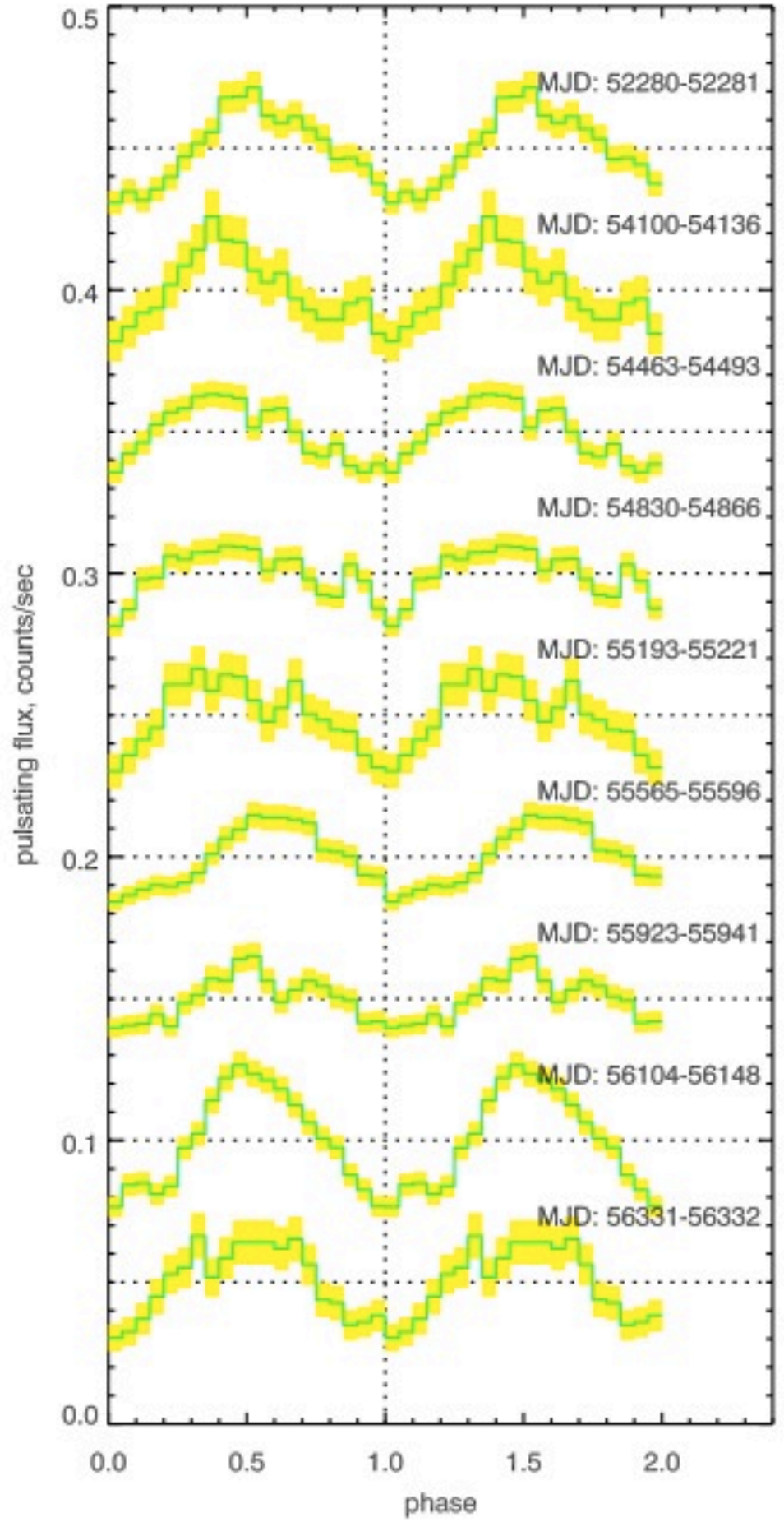
XB091D


Year
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
0.5–10 keV Luminosity [x10³⁹ erg/s²]
1.2
1.0
0.8
0.6
0.4
0.2
Hardness Ratio
10
8
6
4
5.2×10⁴
5.3×10⁴
5.4×10⁴
5.5×10⁴
5.6×10⁴
Epoch [MJD]

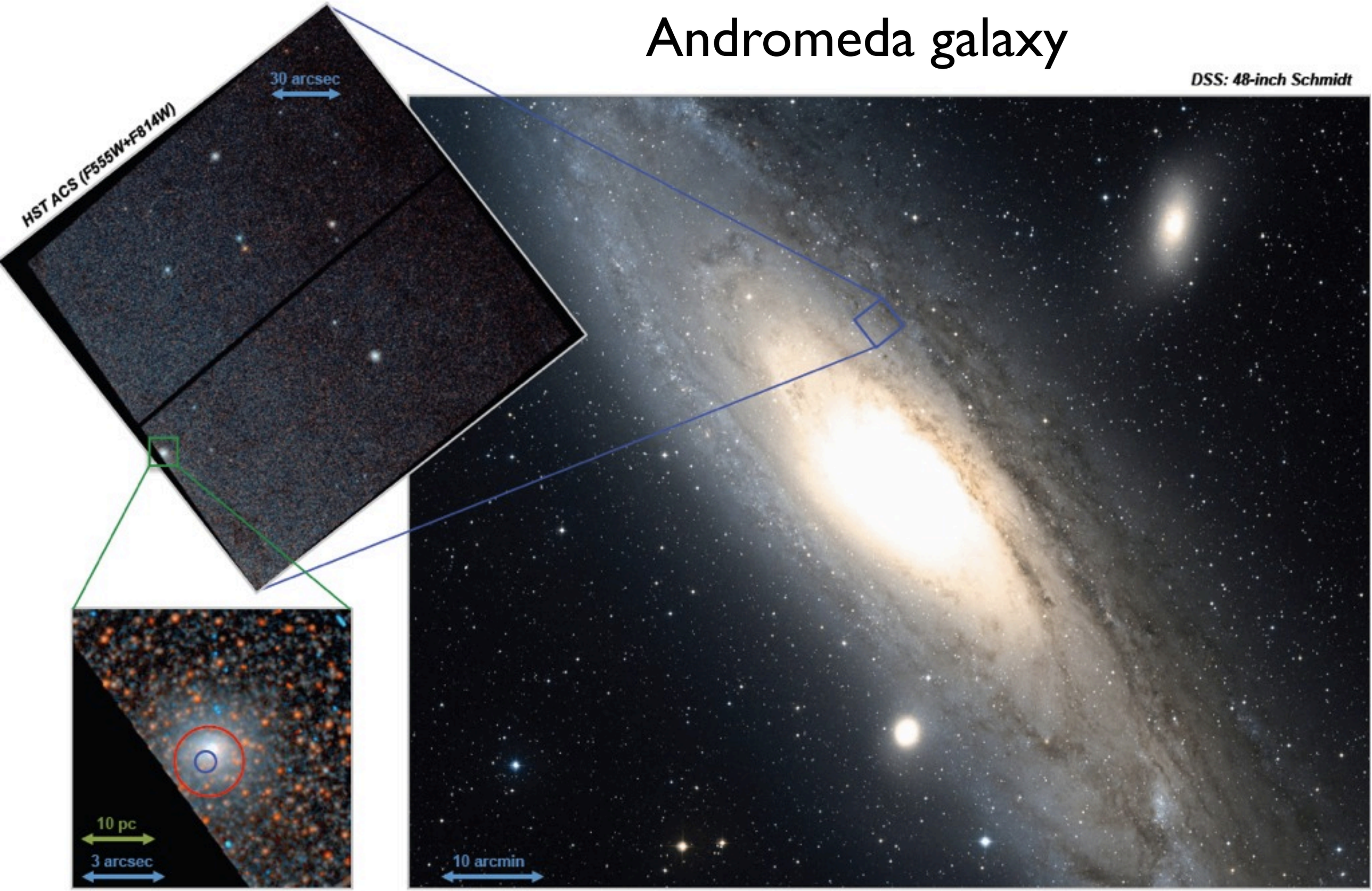

0.1000
0.0100
0.0010
0.0001
Normalized counts keV⁻¹ s⁻¹
4
2
0
−2
−4
χ
1
10
Energy [keV]

XB091D

pulse profiles



Globular cluster B091D in Andromeda galaxy



Terzan 5

- Age: 6 + 12 Gyr
- ρ_0 = 1...4 x 10^6 $M_\odot/pc^3$
- σ_0 = 12.7 km/s
- r_c = 0.24 pc
- $\Gamma_{\text{Terzan 5}}$ = 1
- γ = 13 x γ_{M6}

M31 B091D

- Age: 12 Gyr
- ρ_0 = 8 x 10^5 $M_\odot/pc^3$
- σ_0 = 18.6 km/s
- r_{core} = 0.42 pc
- Γ = 1.5 x $\Gamma_{\text{Terzan 5}}$
- γ = 15 x γ_{M6}

Encounter rate:

$$\Gamma \propto \rho_0^2 r_c^3 / \sigma_0$$

Encounter rate per binary:

$$\gamma \propto \rho_0 / \sigma_0$$

Terzan 5

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Prolific

M31 B091D

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Even more prolific!

Encounter rate:

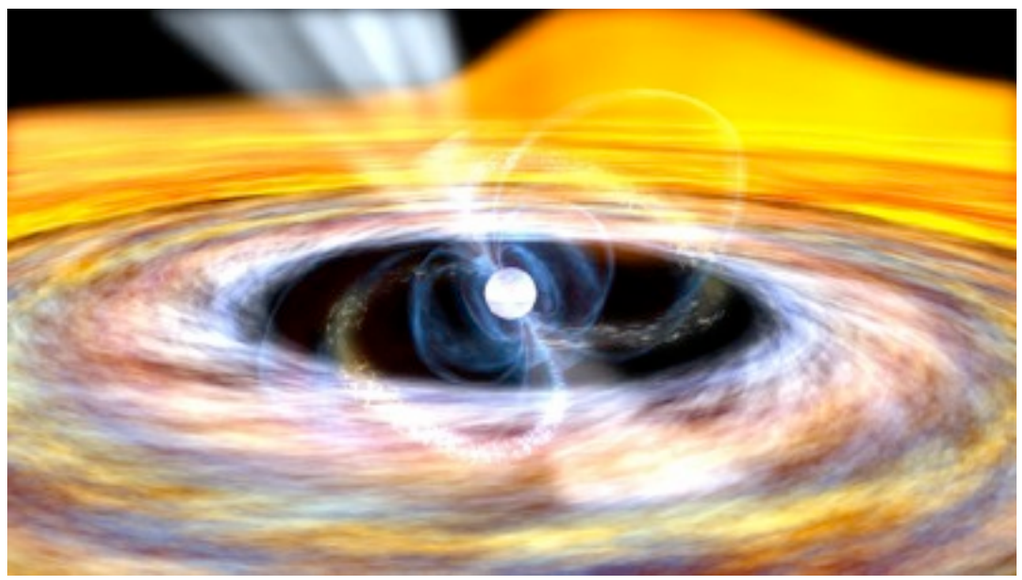
$$\Gamma \propto \rho_0^2 r_c^3 / \sigma_0$$

Encounter rate per binary:

$$\gamma \propto \rho_0 / \sigma_0$$

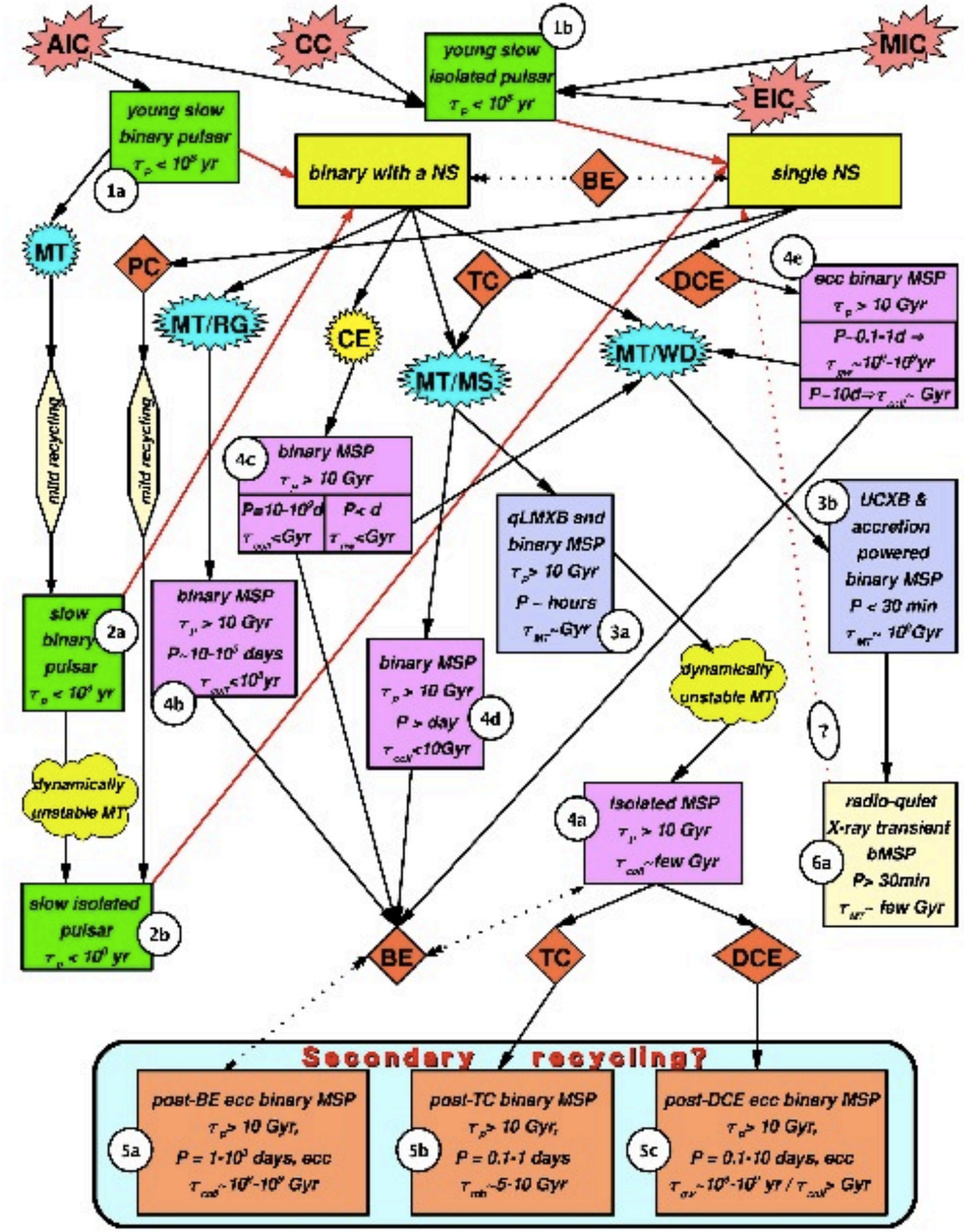
Neutron star

- Corotation radius: 1890 km
- Magnetic field (neutron star radius < accretion disk truncation radius < corotation radius): $2.5 \times 10^8 < B < 10^{12}$ G
- Typical magnetic field decay time: ~100 Myr
- **Must be young**



Formation and evolution of compact binaries in globular clusters

Ivanova et al.(2008)



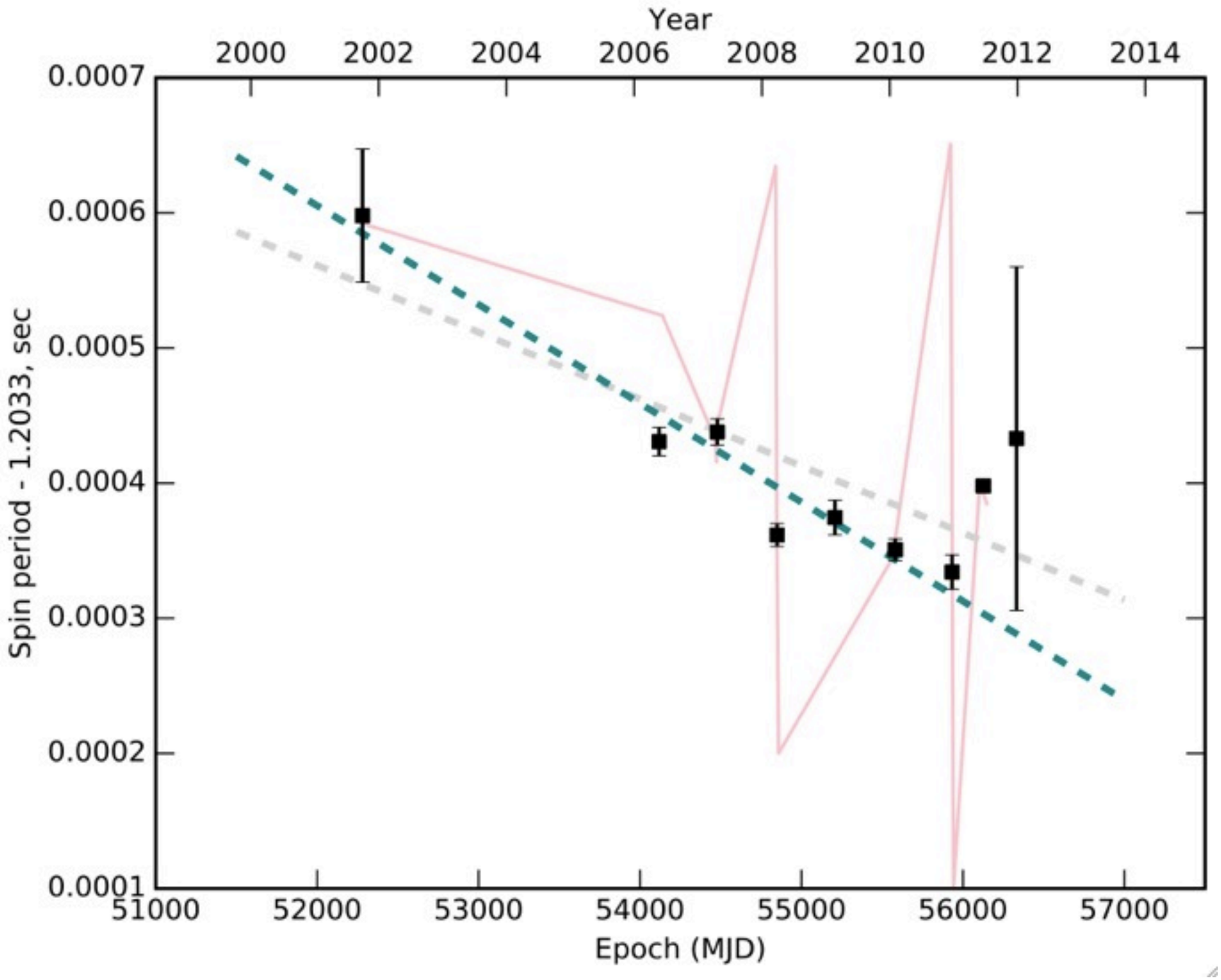
Origin of the system

- NS must have formed recently
- Accretion induced collapse (AIC) is 3 times more effective than all other dynamical events in GC (Ivanova2008)
- 10 AIC-formed LMXBs in GC per 1 Gyr at 12 Gyr
- AIC fits well population of high-B slow *radio* pulsars (Breton2007) and e.g. 4U1626
- Merger induced collapse is also probable

Same donor or not?

- AIC: system loses 0.2 $M_\odot$ due to binding energy → becomes detached
- Time to resume mass transfer? No remaining mass in the companion?
- Disruption before MT resumed?
- From mass function: $0.4 < M_2 < 1.0\ M_\odot$
- Roche lobe: $1.6 < R_{L2} < 2.3\ R_\odot$
- Turnoff mass for 12 Gyr: $0.8\ M_\odot$

Future of this system



Future of this system

- Steady long-term spin-up: ~ 2 x 10^{-5} sec / year, very similar to Terzan 5 pulsar
- In 10^5 years it becomes a normal recycled millisecond pulsar in a binary with P ~ 1 day
- We are very lucky to catch it next to the onset of accretion / recycling

EXTRAS

- Timing with XMM-Newton: studying variability at several timescales
- EU FP7 project
- Esposito et al., MNRAS Letter, Dec 2015
- We do not agree with many their conclusions

Conclusions

- XB091D – second farthest extragalactic pulsar, first known in M31
- Slowest spinning NS in GC
- Widest accreting binary in GC with low-mass subgiant companion $M_2 \sim 0.8\ M_\odot$
- First non-recycled accreting binary, missing link in classical recycling theory
- Looks peculiar, but AIC/MIC origin with possible donor replace can explain it
- Can be reproduced online from http://xmm-catalog.irap.omp.eu

Thank you