Using very-faint LMXBs to probe ultra-dense matter

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Galactic LMXBs

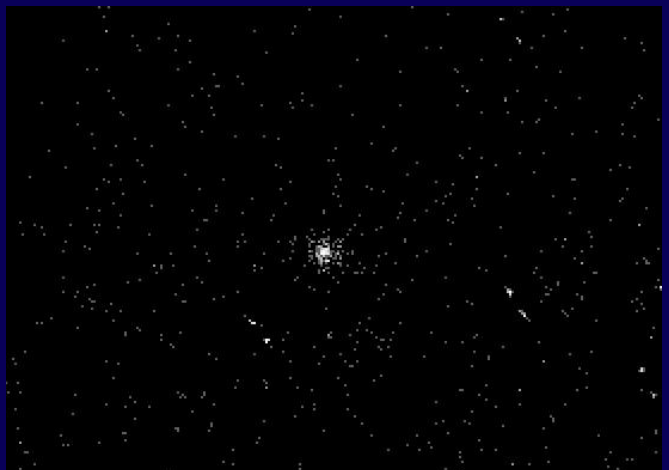
Note the energy range used

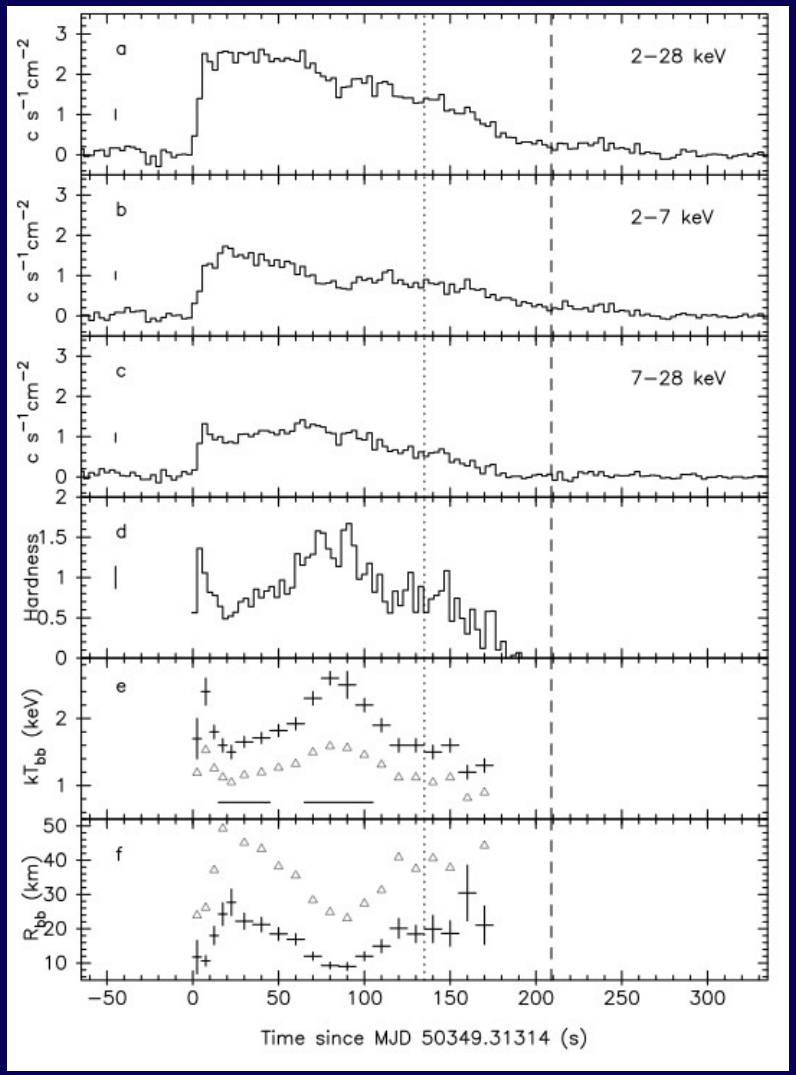
Class	L_x (2-10 keV)	Persistent	Transient
Bright to very bright	$10^{37\text{-}39}$ erg s^{-1} $\gtrsim$10% L_{Edd}	• Mostly NS systems	• Mostly BH
Faint	$10^{36\text{-}37}$ erg s^{-1} ~1-10% L_{Edd}	• Mostly NS systems	• Mostly NS • At least some ultra-compact
Very faint	$10^{34\text{-}36}$ erg s^{-1} ~0.01-1% L_{Edd}	• Only confirmed NSs	• Mostly NS systems? • Ultra compact? • BD/planet companion?

Arbitrary, inspired by observations!

Very-faint persistent NS systems

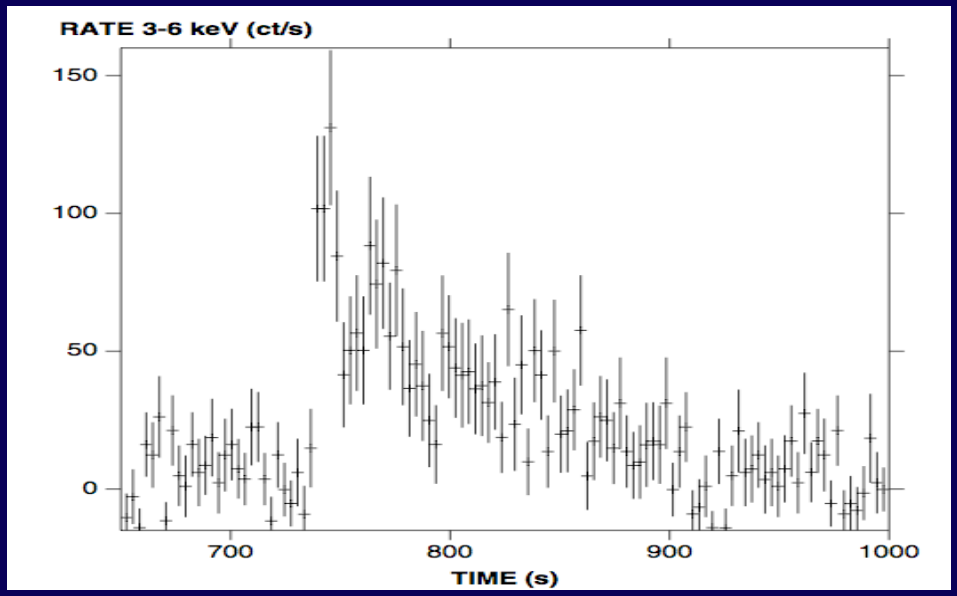
- 1RXS J171824.2-402934 and 1RXS J173523.7-354013
  - In ‘t Zand et al. 2005
    - ~10^{34} and ~10^{35} erg s^{-1}
- AX J1754.2-2754
  - Sakano et al. 2002
  - Chelovekov et al. 2007
  - Del Santo et al. 2007
    - ~3 x 10^{34} erg s^{-1} (2-10 keV)

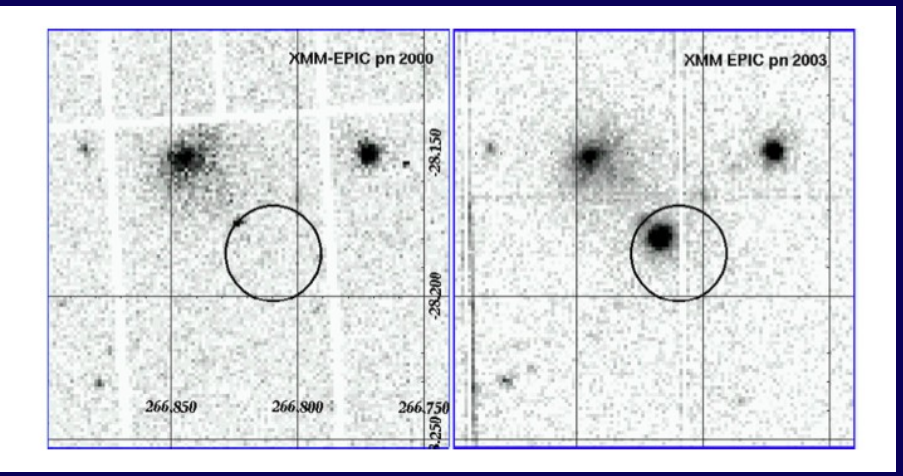


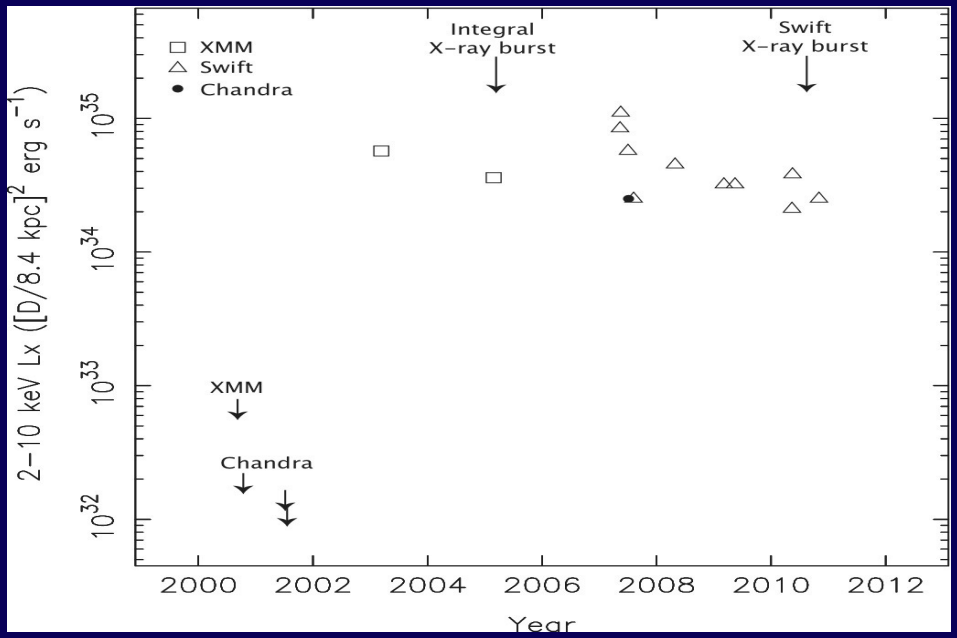


Very-faint quasi-persistent NS sources

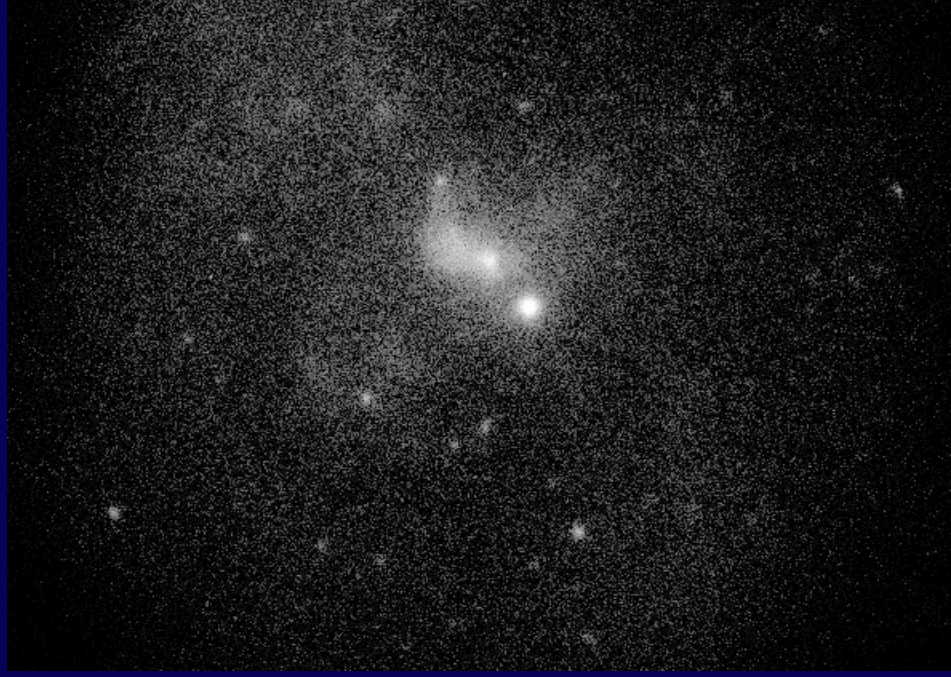
- XMMU J174716.1-281048
  - Sidoli & Mereghetti 2003
  - Del Santo et al. 2007, 2009-11
  - Degenaar et al. 2011
  - 5 x 10^{34} erg s^{-1}

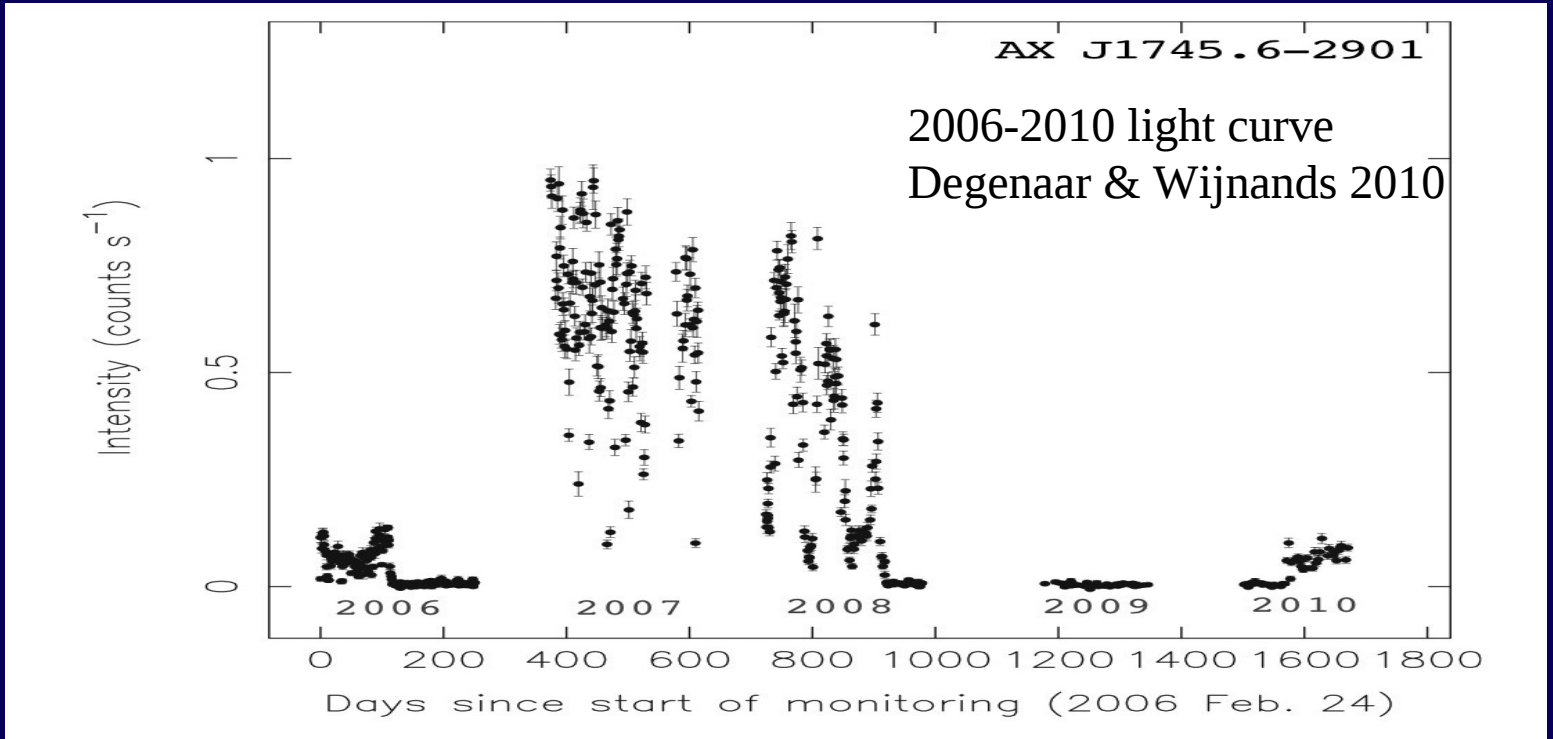






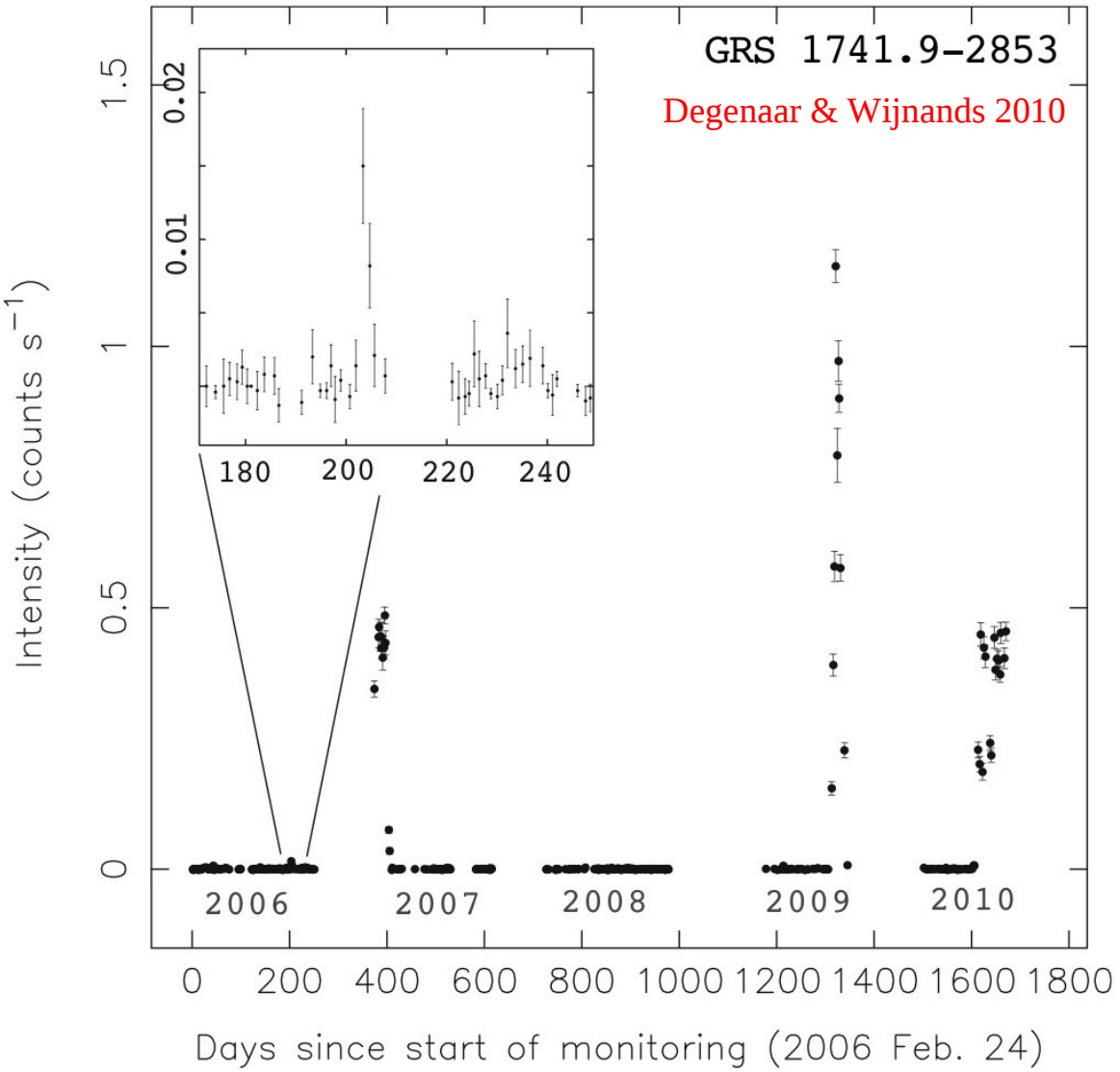
- AX J1745.6-2901
  - Maeda et al. 1996
    - 8 hr eclipsing system
  - Swift J174535.5-290135.6
    - Kennea et al. 2006
    - < 5 x $10^{35\text{-}36}$ erg s^{-1}

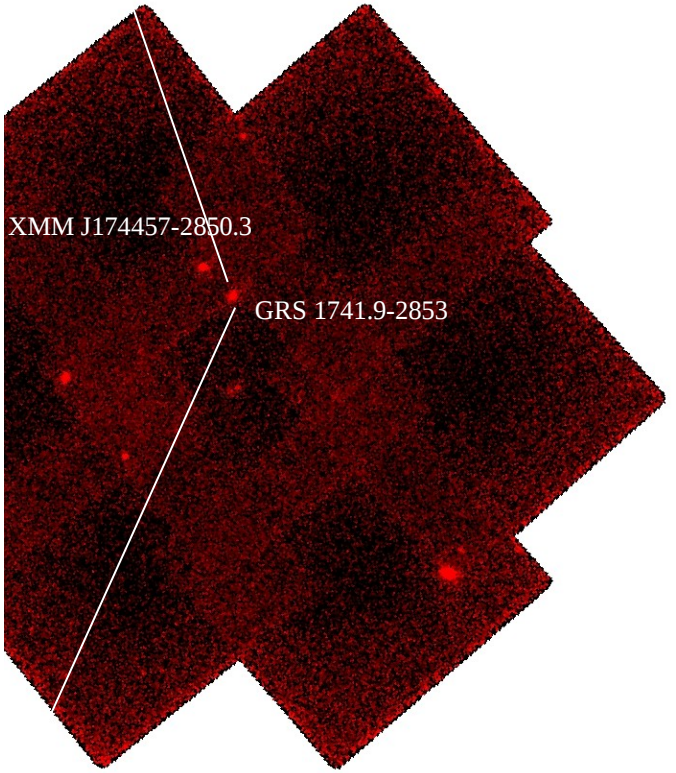




Very-faint transient X-ray binaries

g s^{-1}





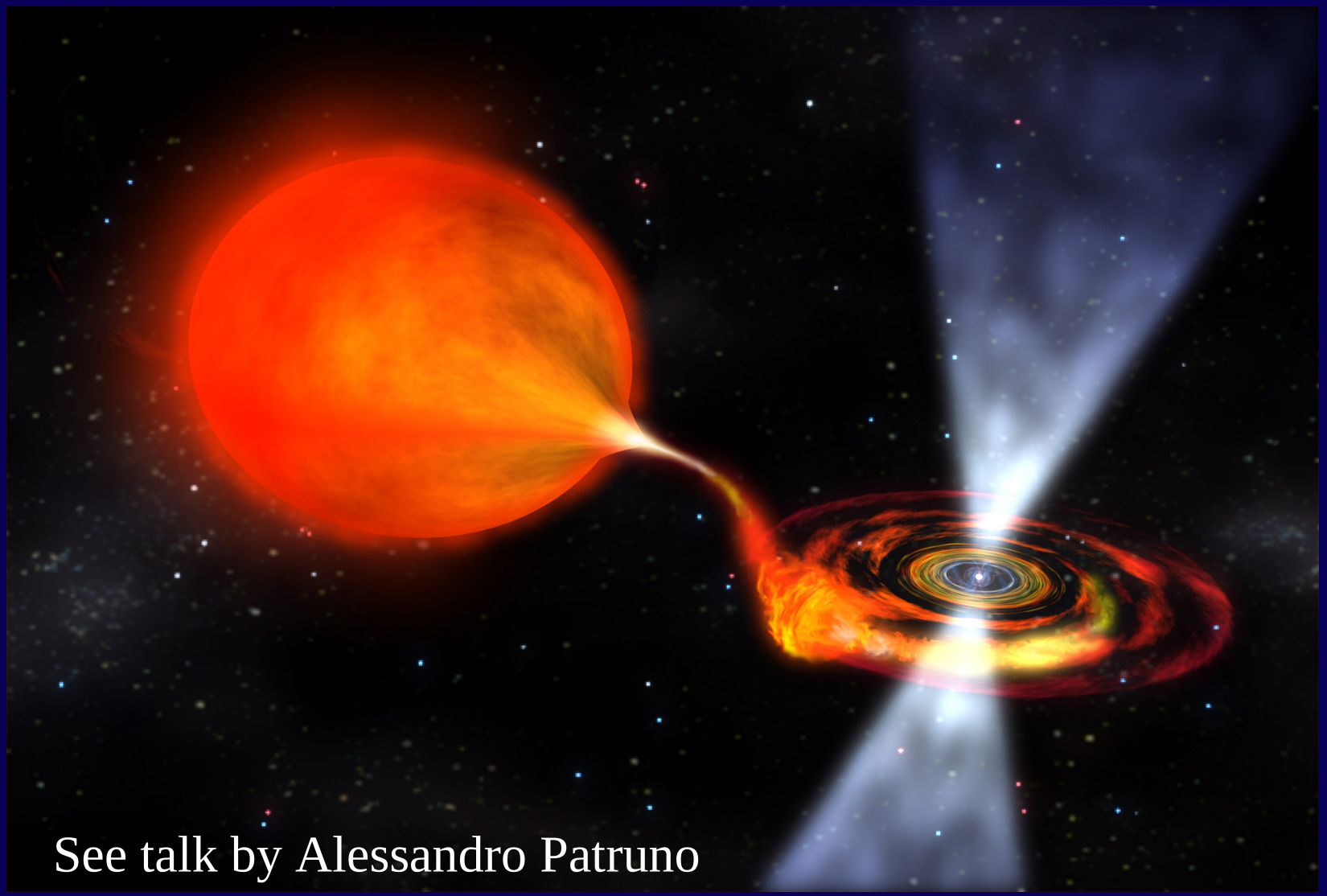
Wijnands et al. 2006

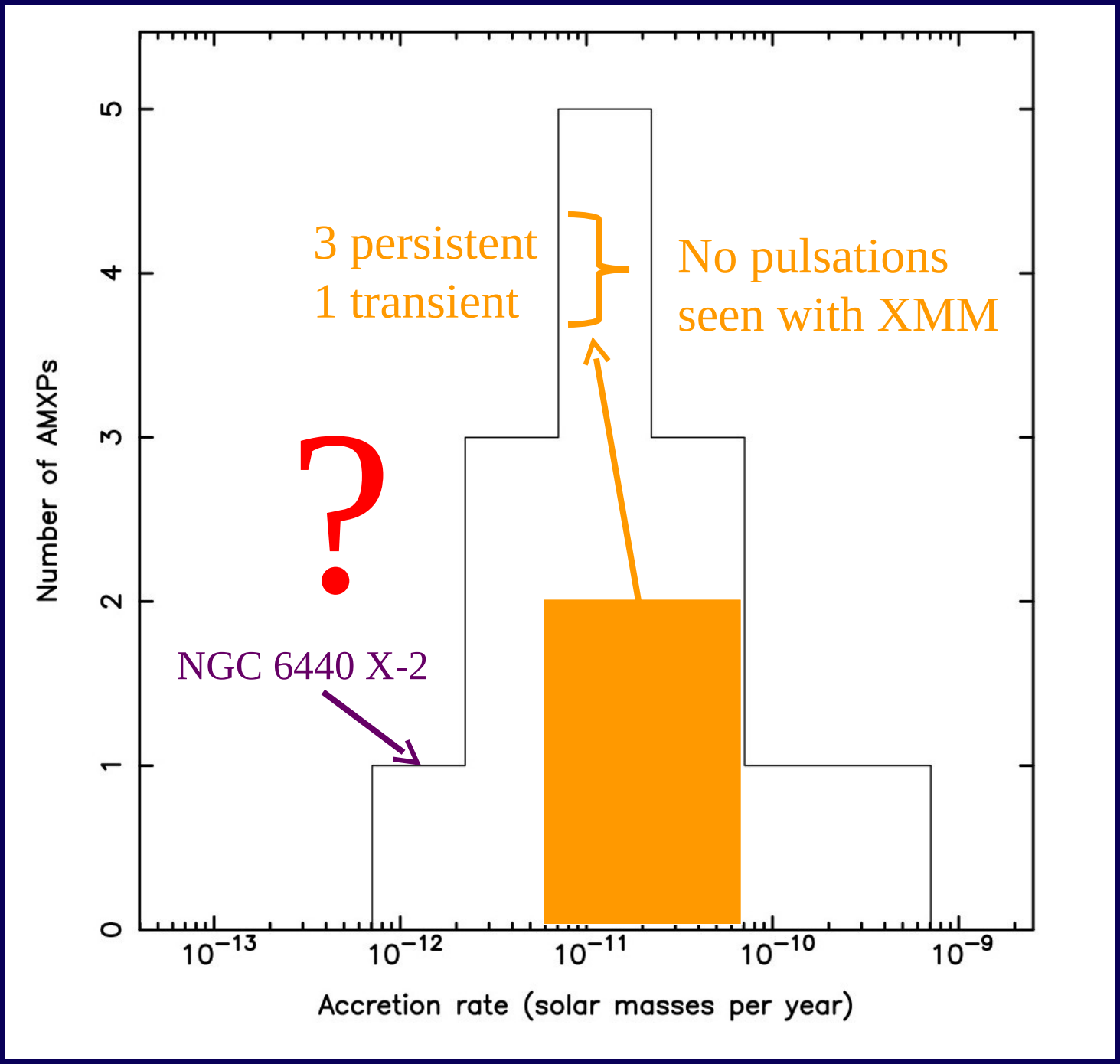
Binary evolution and population synthesis

- What kind of binary and how are they formed?
  - Orbital period, companion star
  - Why are they so faint?
- How many in our Galaxy and where located?
  - Are we ignoring a large population or not?
  - A few arcminutes to >100 degrees from Sgr A*
    - Averaged distance from Sgr A* ~ 17 degrees
- Where are the black hole systems?
- What can we learn about NSs?

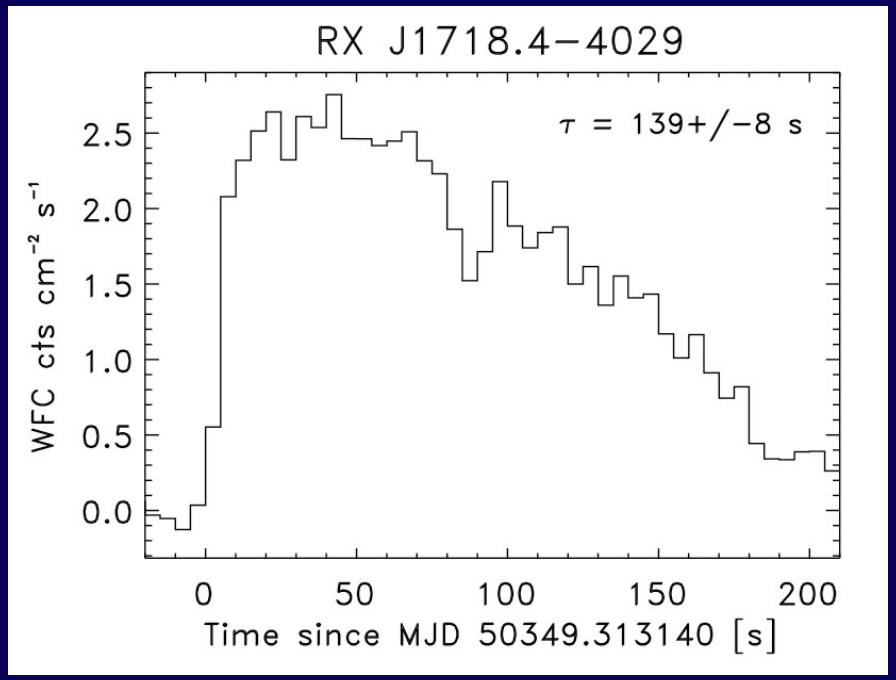
What can we learn about NSs?

- Accreting millisecond X-ray pulsars

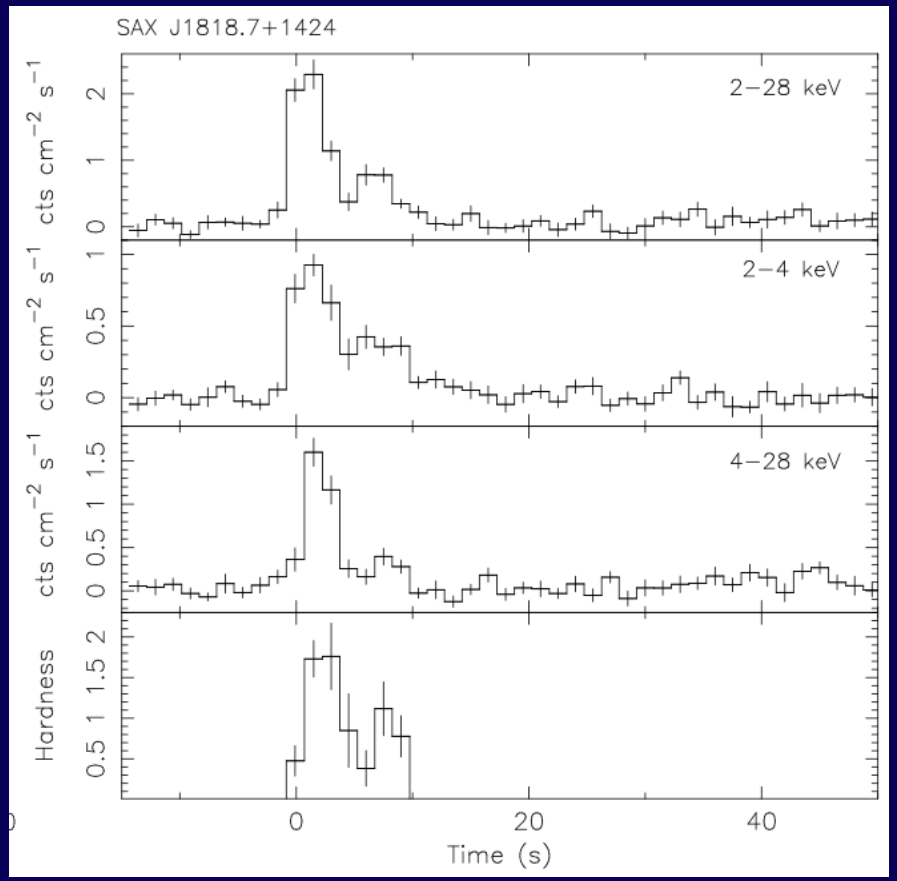



3 persistent
1 transient
No pulsations
seen with XMM
?
NGC 6440 X-2
Number of AMXPs
0
1
2
3
4
5
10^{-13}
10^{-12}
10^{-11}
10^{-10}
10^{-9}
Accretion rate (solar masses per year)

- Thermonuclear flashes
  - New accretion rate regime
  - Peng et al. 2007
  - Cooper & Narayan 2007

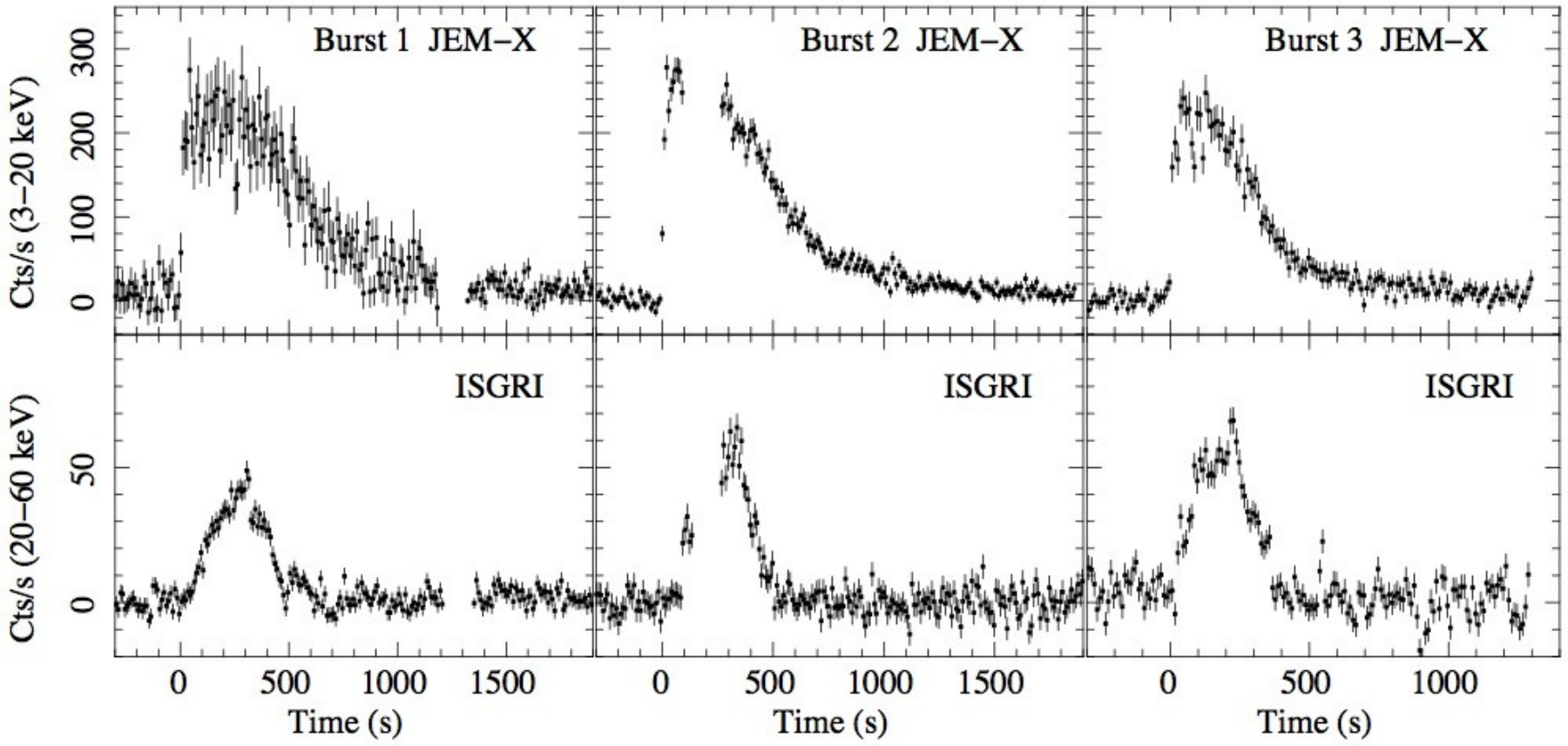


In ‘t Zand et al. 2007



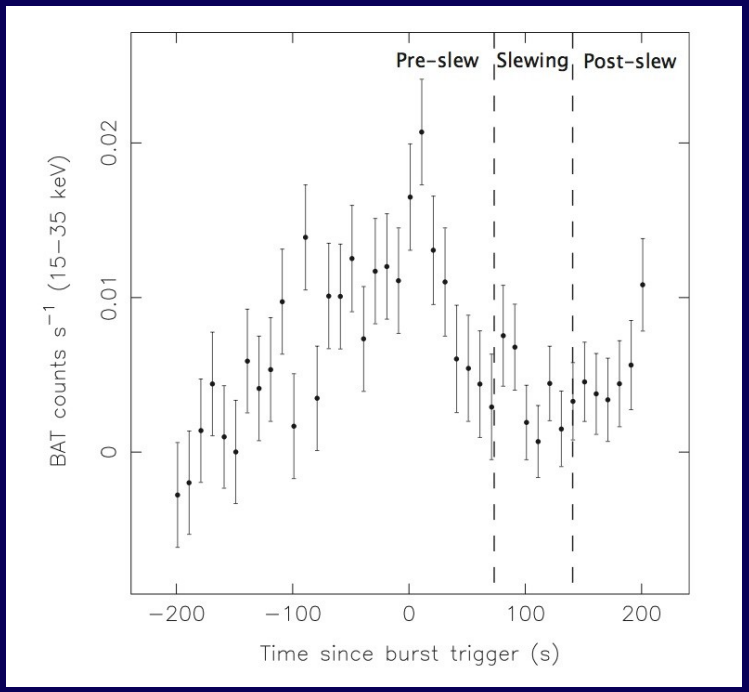
Cornelisse et al. 2003

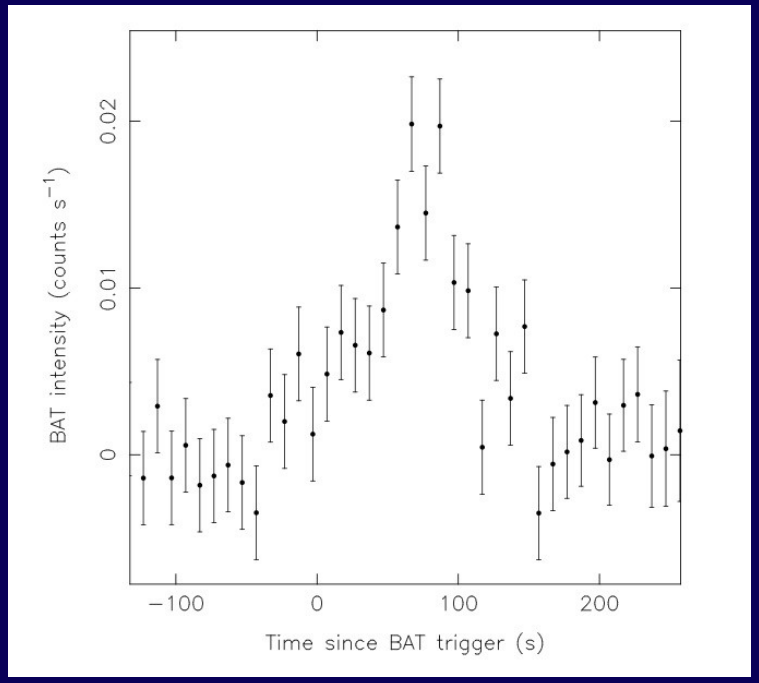
Intermediate long bursts

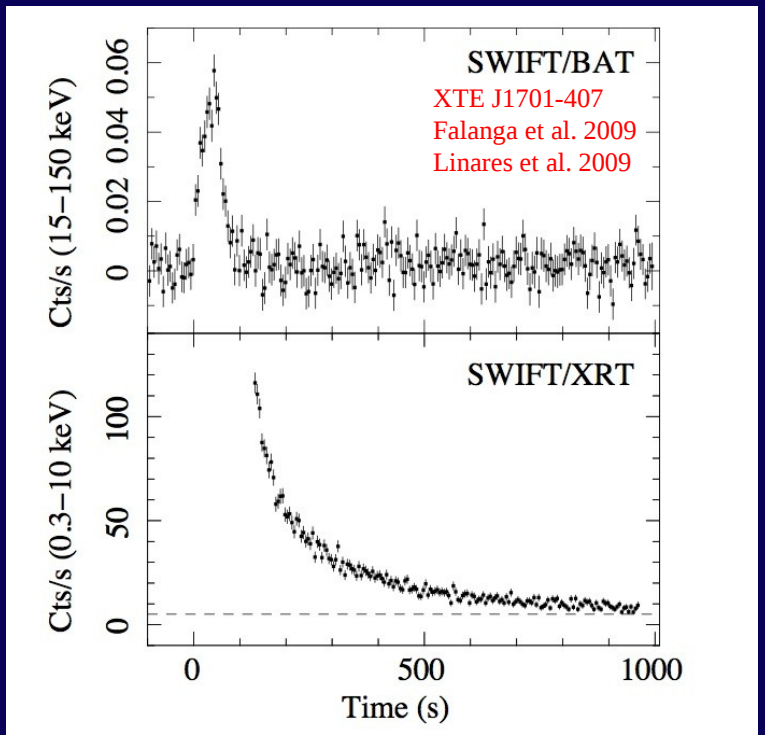


SLX 1737-282: Falanga et al. 2008

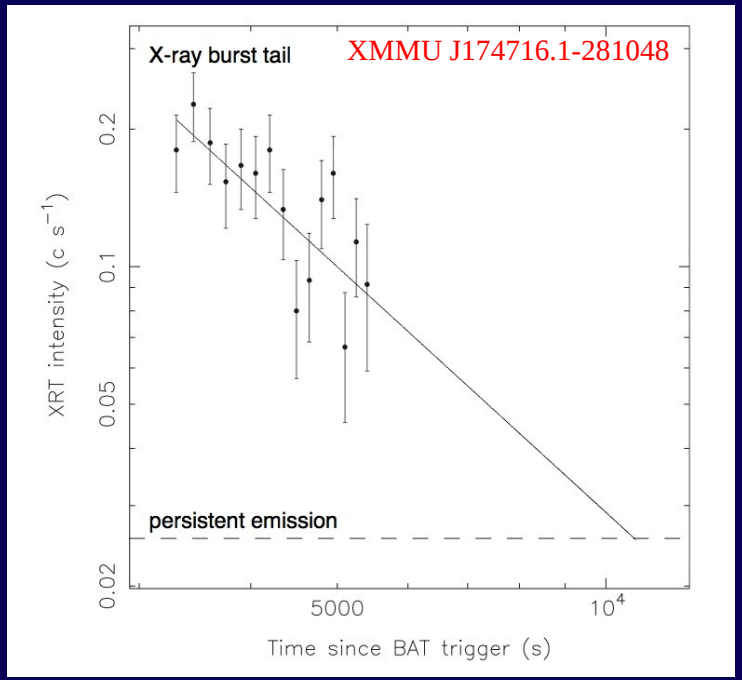
See talks of Jérôme Chenevez and Ed Brown





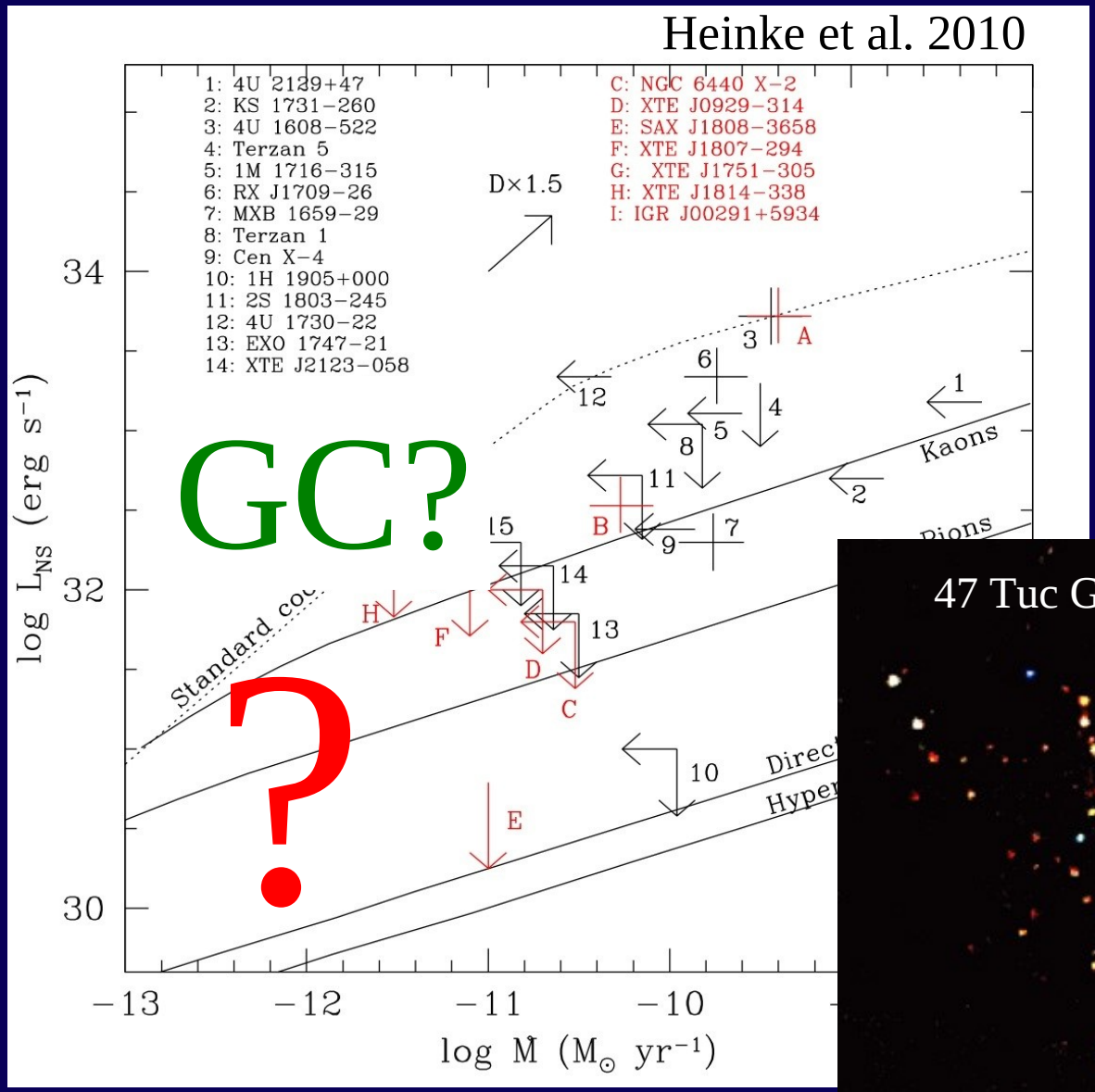


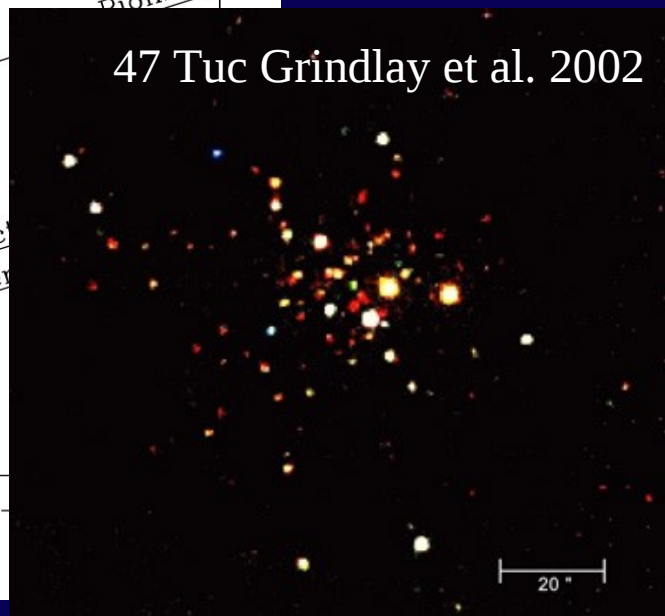
Degenaar et al. 2010, 2011



- Cooling of accretion heated neutron stars

Heinke et al. 2010

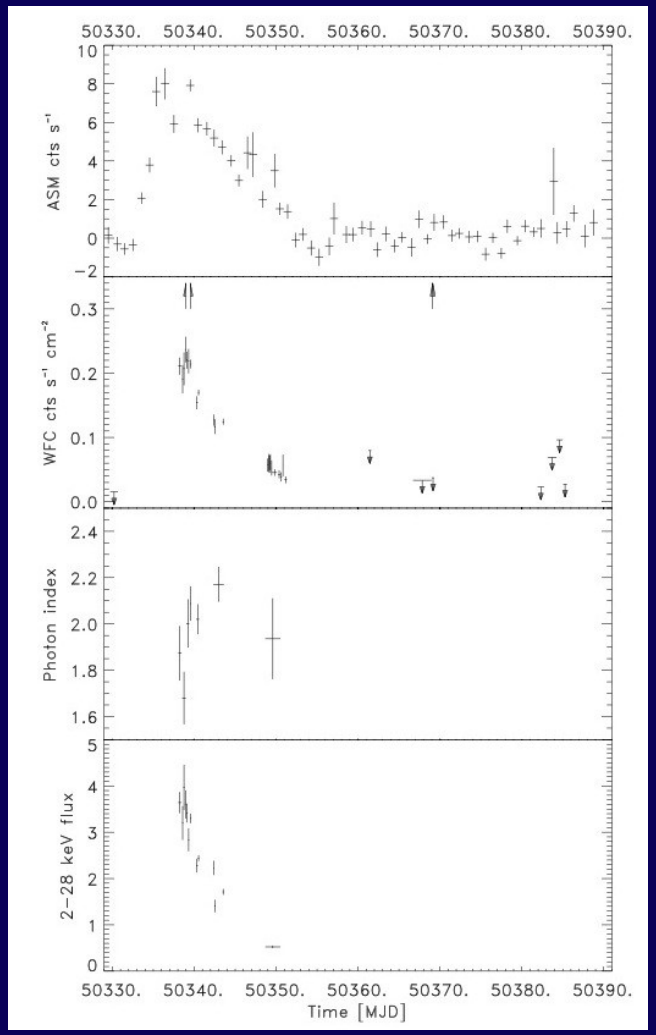


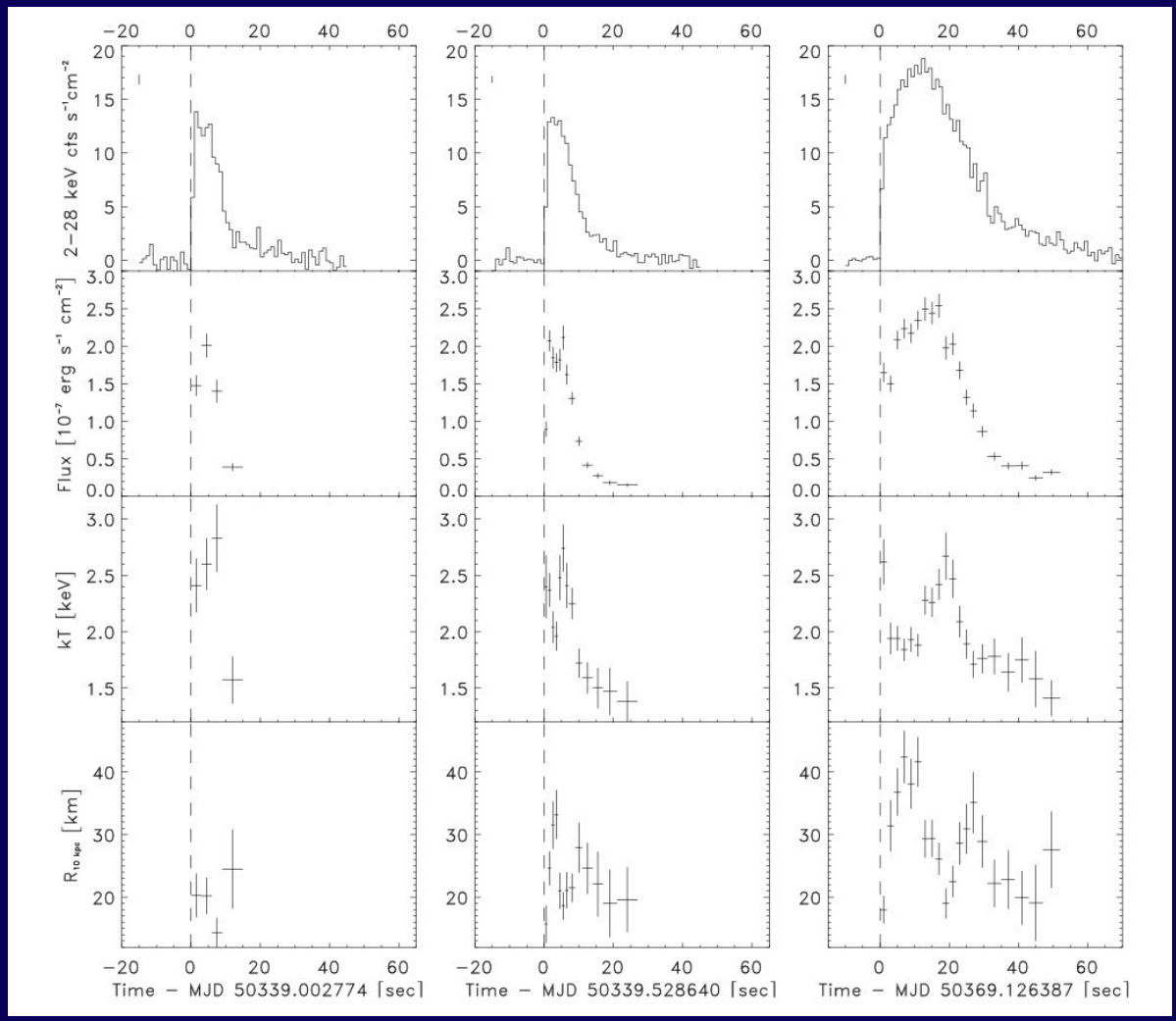


Conclusion

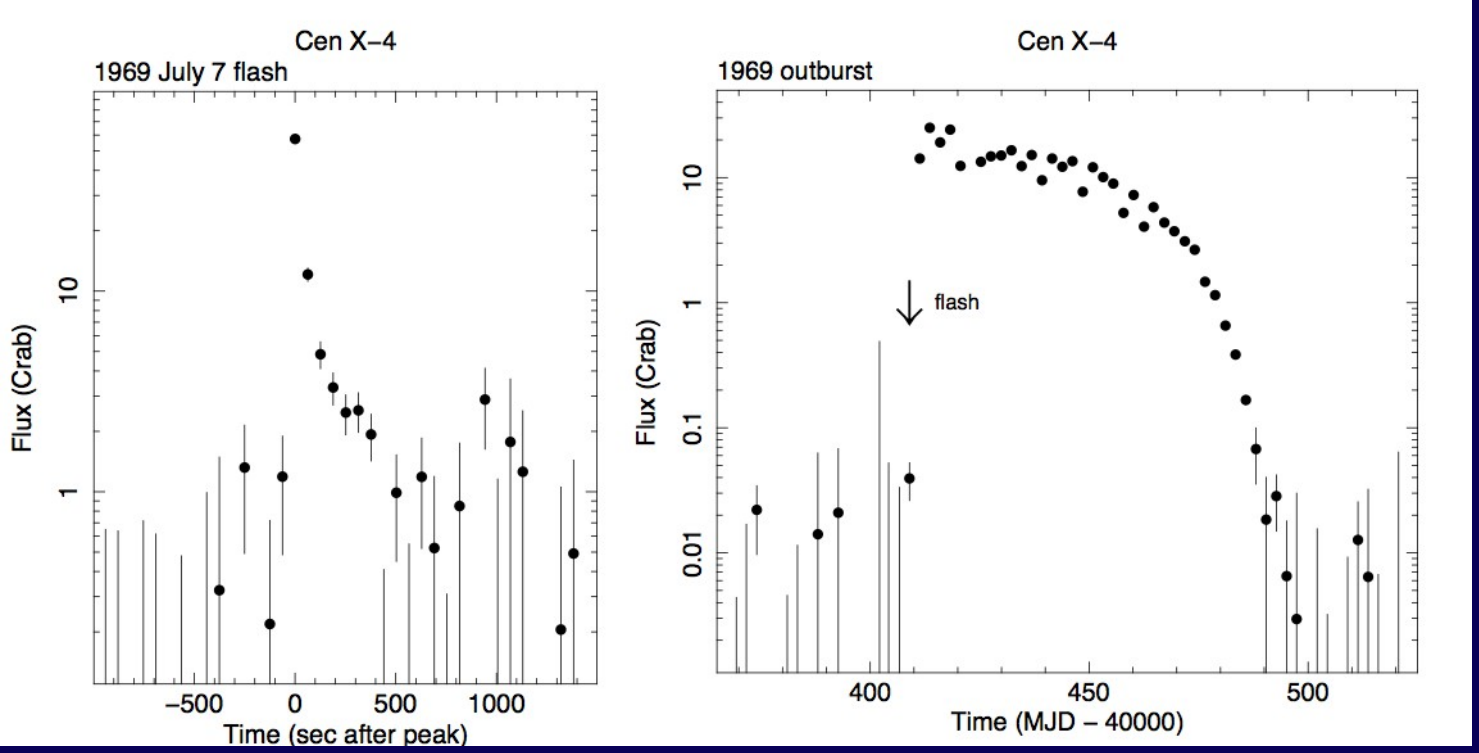
- A variety of sub-luminous accreting NS LMXBs
  - Difficult to find and get high quality data
    - But making progress!
    - Finding more sources: eRosita/NuSTAR
    - LOFT to study rapid variability
    - Sensitive all-sky monitors
- New insights into fundamental (astro-)physics
  - NS properties
  - Accretion and binary evolution
  - Comparison with bright transients at very low Mdot

Comparison with bright transients





SAX J1808.-3658: In ‘t Zand et al. 2001



Kuulkers et al. 2009

GRS 1747-312
In ‘t Zand et al. 2003