Discovery of a new transient in Terzan 5

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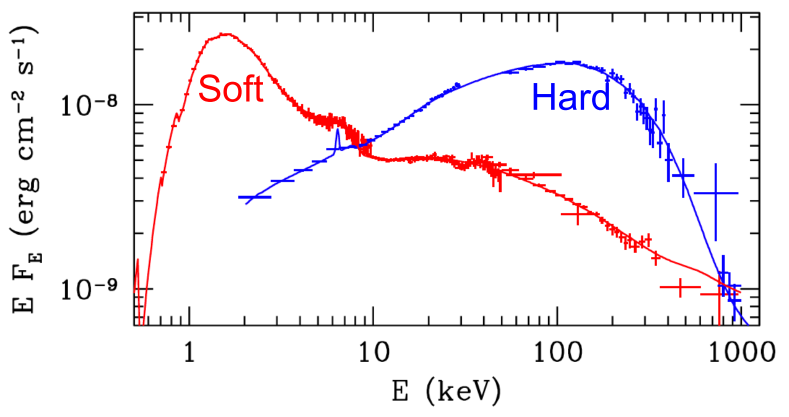
Spectral evolution of NS LMXB outburst cycle

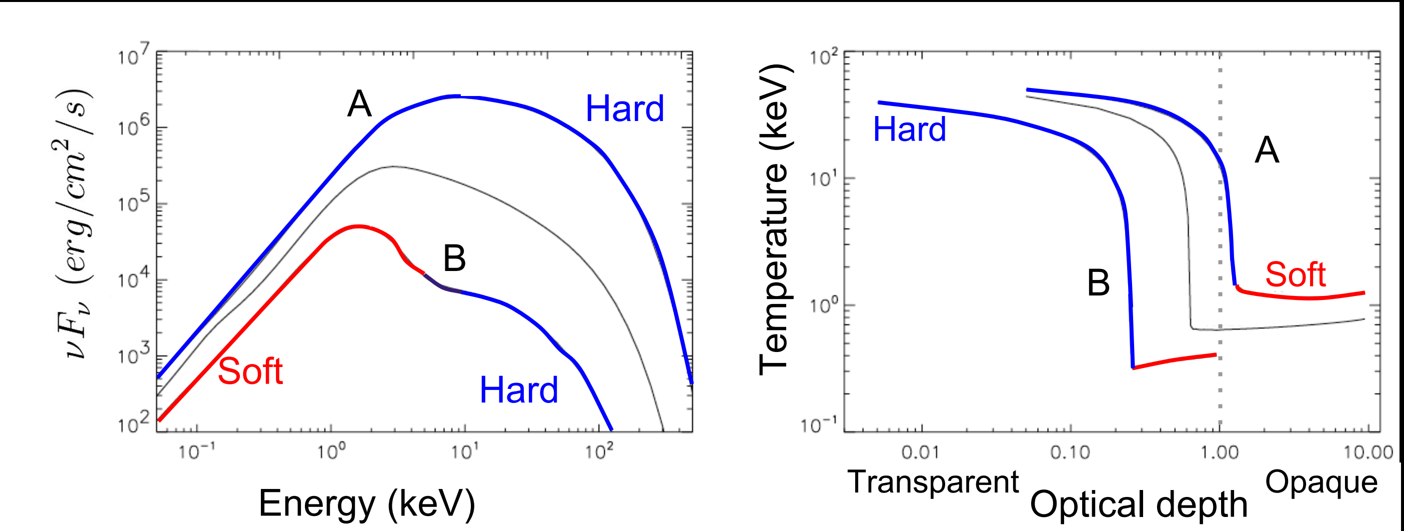
- High-Soft state: Optically thick accretion disk; $L_X > 10^{37}$ erg/s
- Low-Hard state: Comptonized corona; below $L_X \sim 10^{37}$ ergs/s
- Quiescent state: Very soft, from NS surface; $L_X < 10^{34}$ erg/s



Hard (blue) and soft (red) states of Cyg X-1 (Gierlinski et al 1999)

Theory: Continuing accretion in LMXBs

- Hard state: Infalling material Comptonizes
- Lower fluxes: Cooler atmosphere visible



A: High accretion rate, L~10^{36} erg/s

B: Low accretion rate, L~10^{34} erg/s

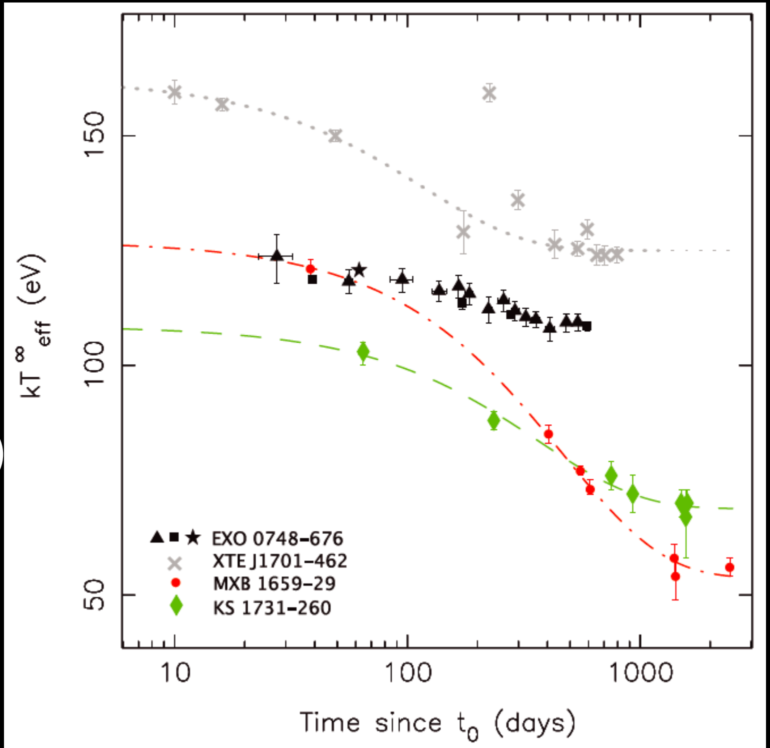
(Deufel et al. 2001)

Theory: Cooling of NS LMXB after outburst

Crust cooling: leakage of the heat stored during accretion from NS's crust.

Observed in several LMXBs after outbursts

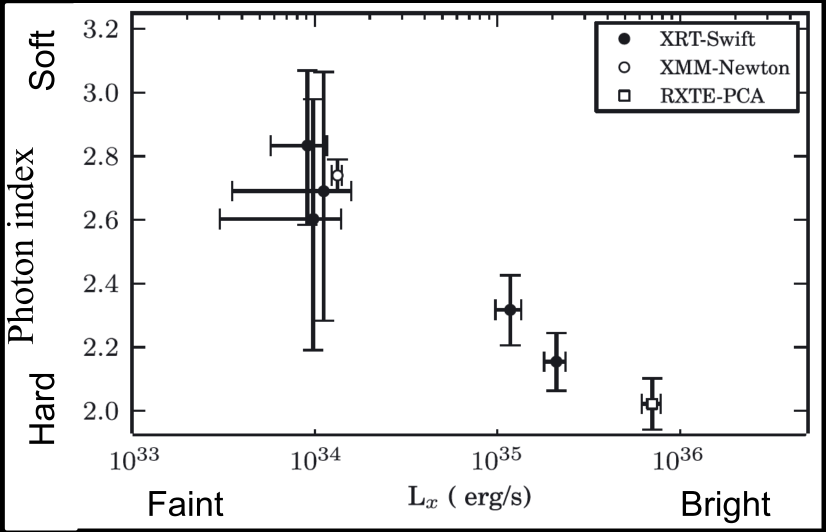
(e.g. Cackett+06, Degenaar+11, etc.)



Decay of NS temperatures post-outburst
(Degenaar et al. 2011)

Spectral evolution during outburst decay

- As L_x decays, cooler thermal emission (from NS) appears; from **falling matter onto NS** or **cooling NS crust**?



Spectral softening during outburst decay

(Armas Padilla et al. 2011)

Spectral evolution during rise of outburst

- Test through rise of outburst:
    - If thermal component present:

      powered by accretion during rise and decay

    - If no significant thermal contribution:

      low-level accretion gives only non-thermal emission

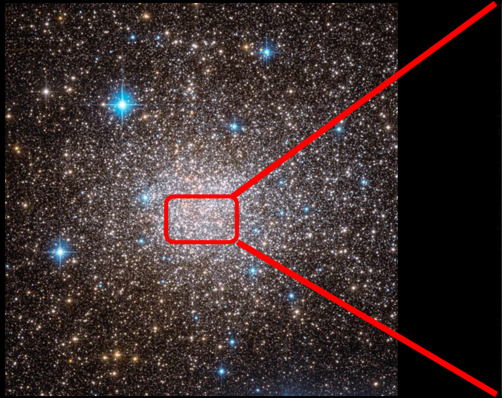
      cooling crust provides thermal emission in decay

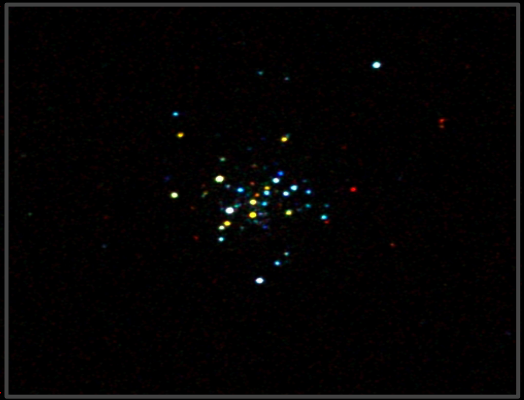
Terzan 5: Best target to catch outbursts

- Two previously known bright X-ray transients
- 50 other X-ray sources (Heinke+06), 33 radio pulsars (Ransom+05)
- We monitored with Swift to look for faint X-ray outbursts

Terzan 5
Optical image

Credit: Hubble Space Telescope (NASA/ESA)



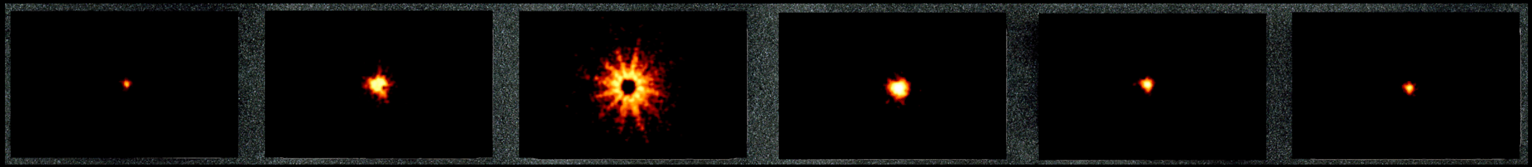


Terzan 5
X-ray image

Credit: Bahramian et al., Chandra X-Ray Observatory (NASA)

Swift/XRT monitoring

- Monitored Terzan 5 weekly with Swift/XRT in 2012
- Terzan 5 X-3 brightened in July 2012:
  - Identified rising L_X at ~5e34 erg/s
  - Complete monitoring of the outburst

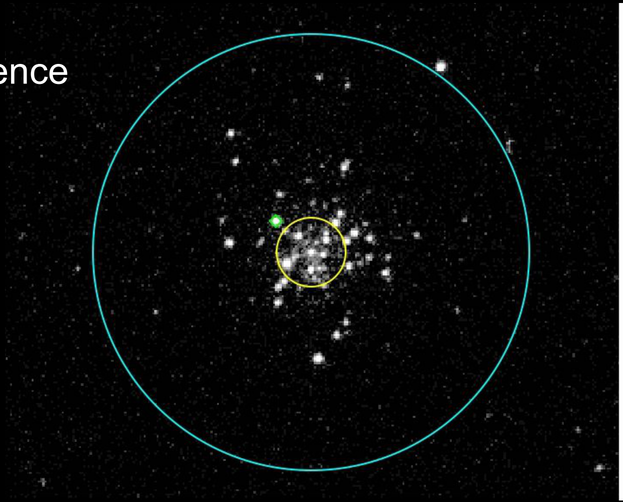


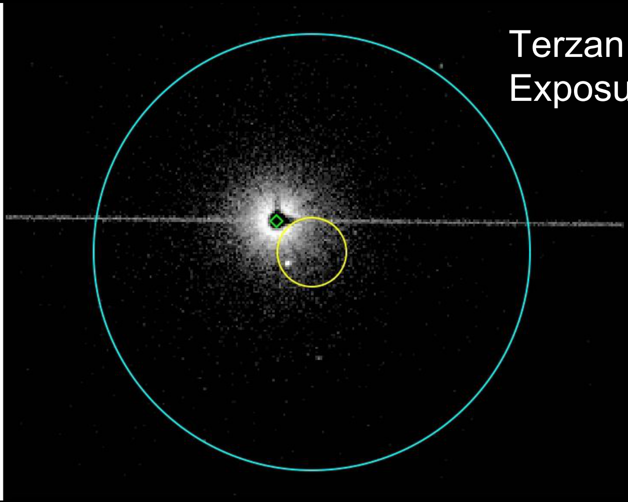
Some of Swift/XRT observations of Terzan 5 X-3

Determining location and identification

- Terzan 5 X-3's position consistent with a previously identified quiescent NS LMXB.
- Detected X-ray burst, confirming NS nature.

Terzan 5 in quiescence
Exposure: 240 ks
(Combined)

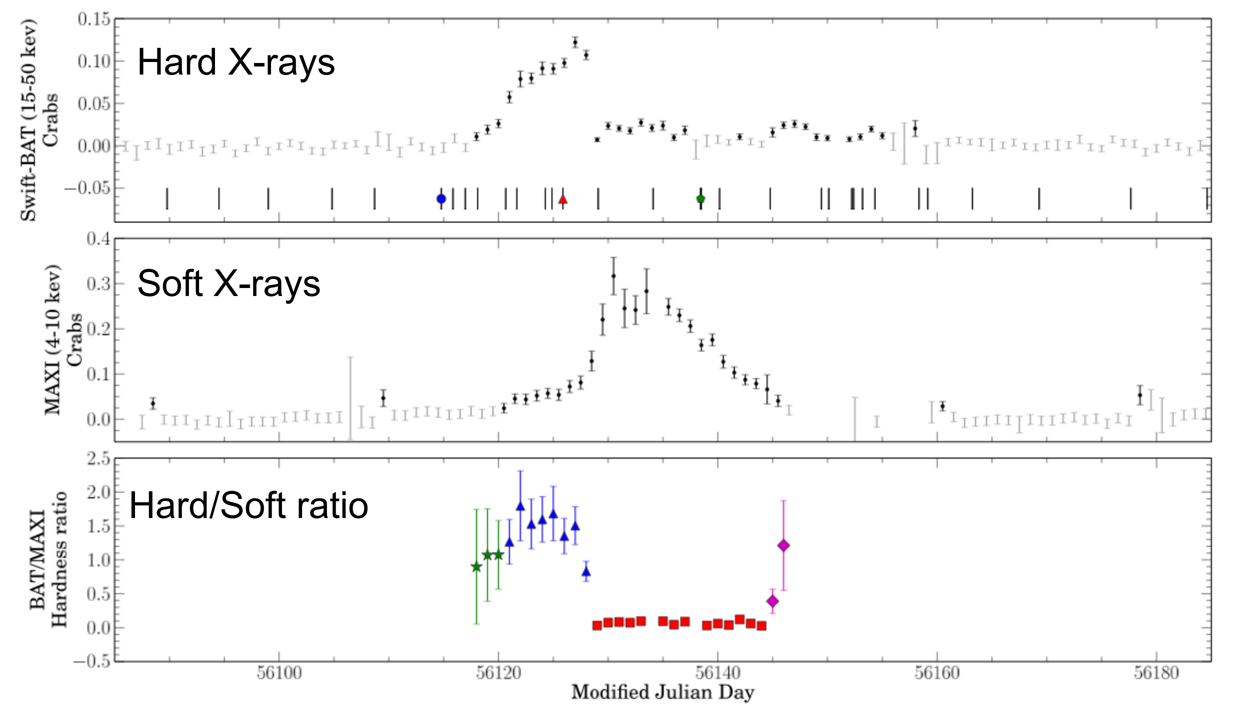




Terzan 5 X-3 in outburst
Exposure: 10 ks

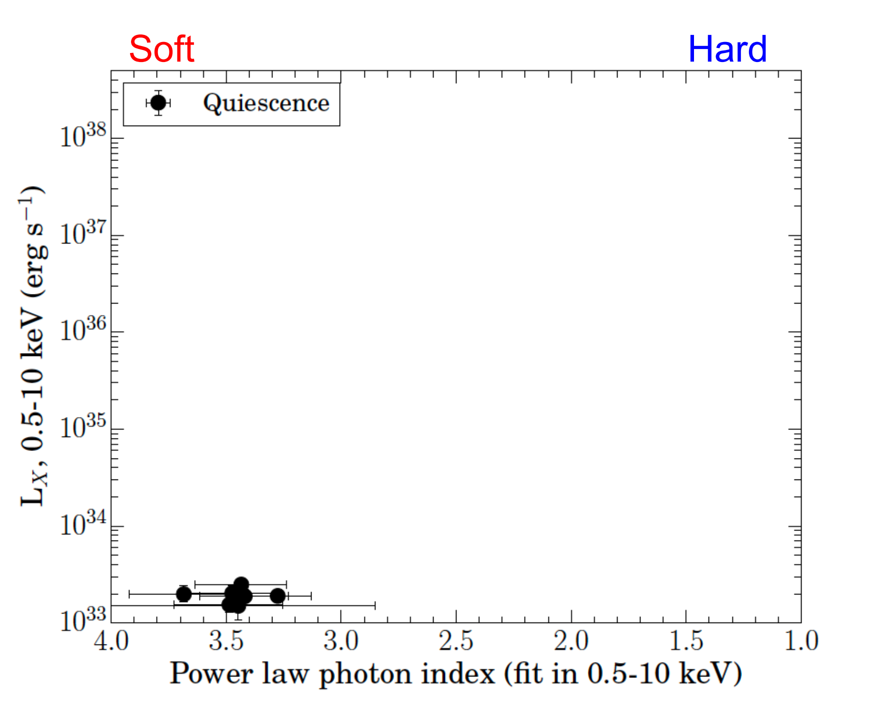
Chandra/ACIS images of Terzan 5

Outburst spectral analysis

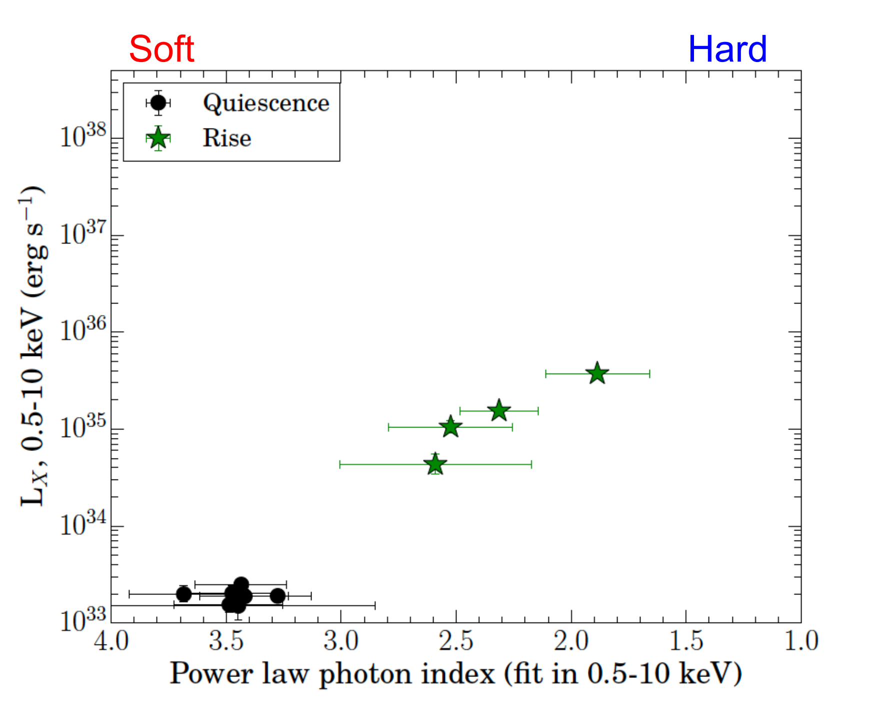


Lightcurve of Terzan 5 X-3 outburst based on observations from Swift/BAT & MAXI. (Bahramian et al. 2014)

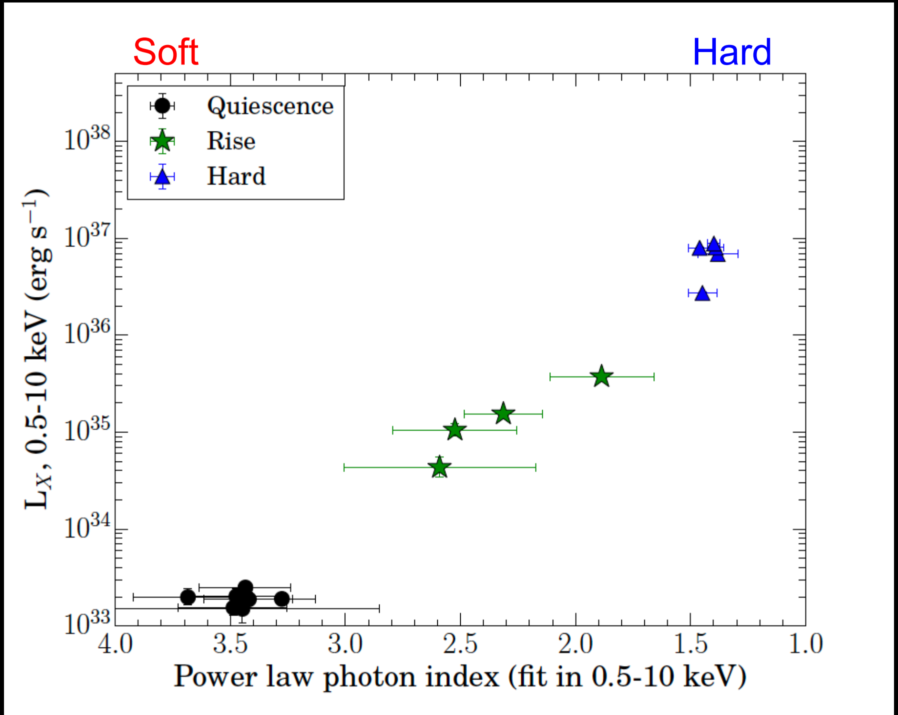
Spectral evolution



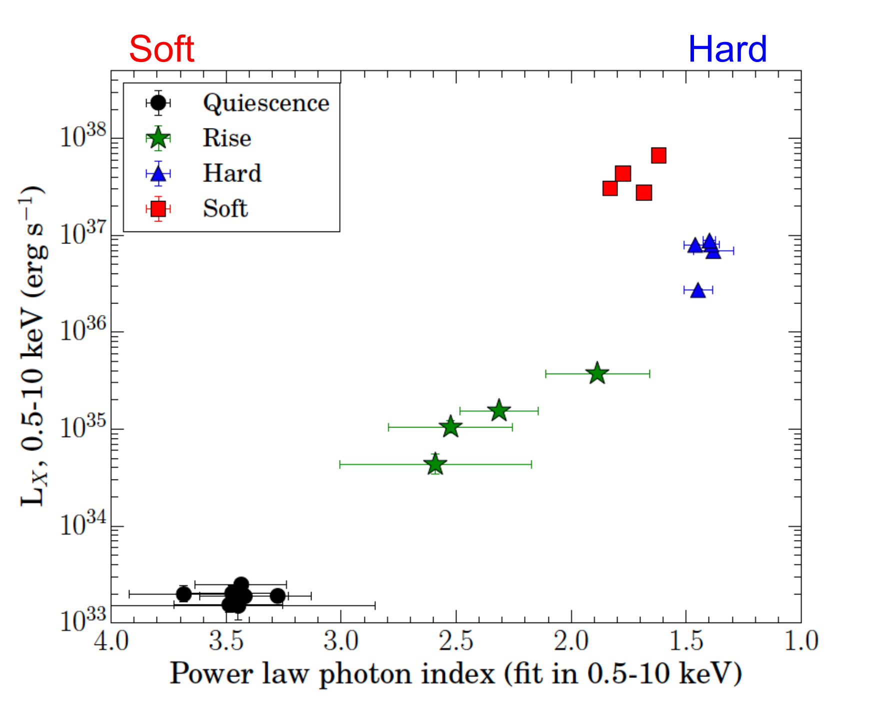
Spectral evolution



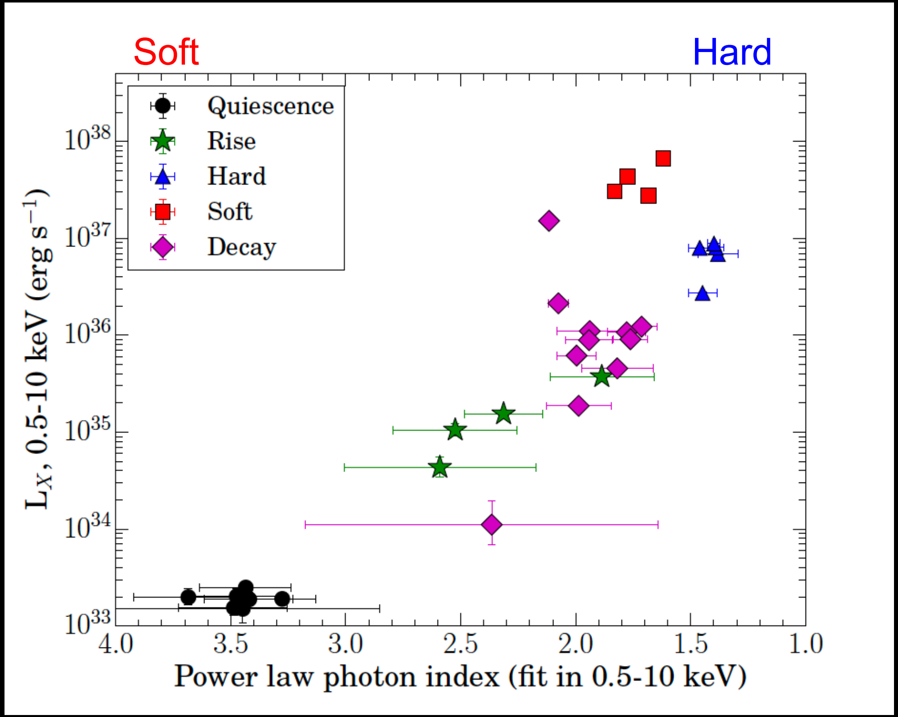
Spectral evolution



Spectral evolution

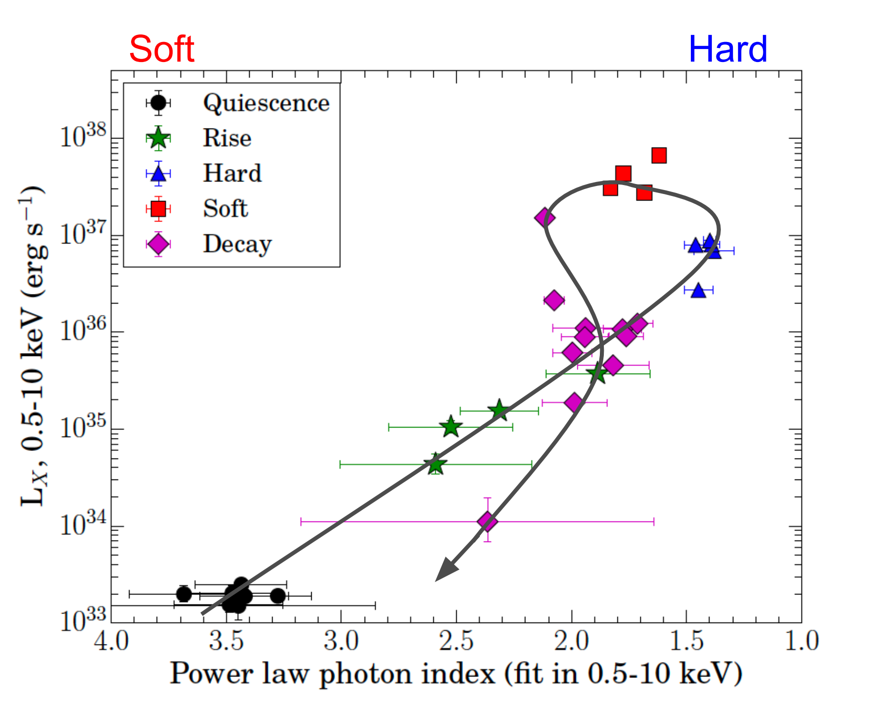


Spectral evolution



Spectral evolution

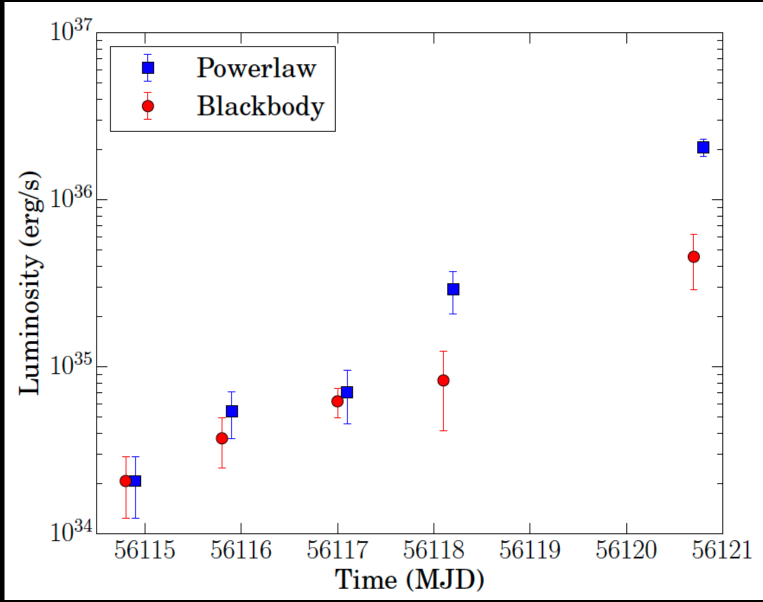
- First evidence of hardening of the spectrum from 5e34 up to 1e36 erg/s.
- Possible only by intensive Swift monitoring.



Spectral evolution of the source; Chandra in quiescence (black), Swift/XRT in outburst (coloured).

Spectral evolution: Rise

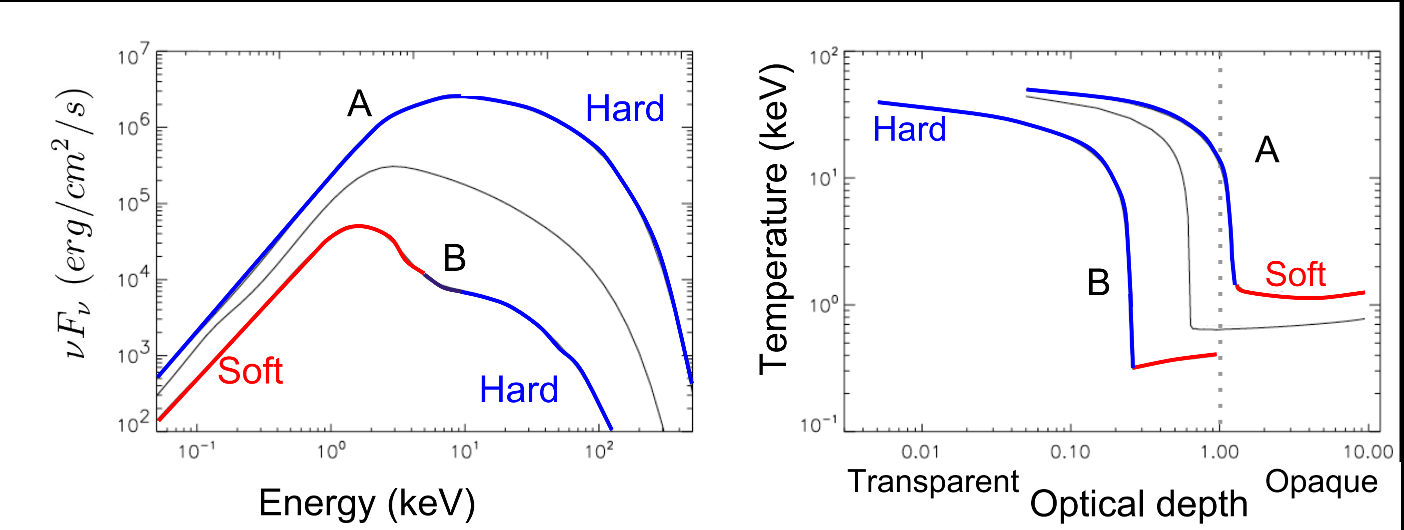
- Thermal component required in fits
- Non-thermal component dominates at the end of rise
- Blackbody gives R=4.3+-1.3 km; from (part of) NS surface



Luminosity of the two components during rise (blue squares shifted to right for clarity)

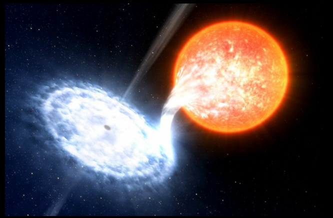
Evolution during outburst rise

- Detected thermal component, & its relative weakening during rise for the first time
- Evidence for contribution from accretion (instead of crust cooling) during rise and fall



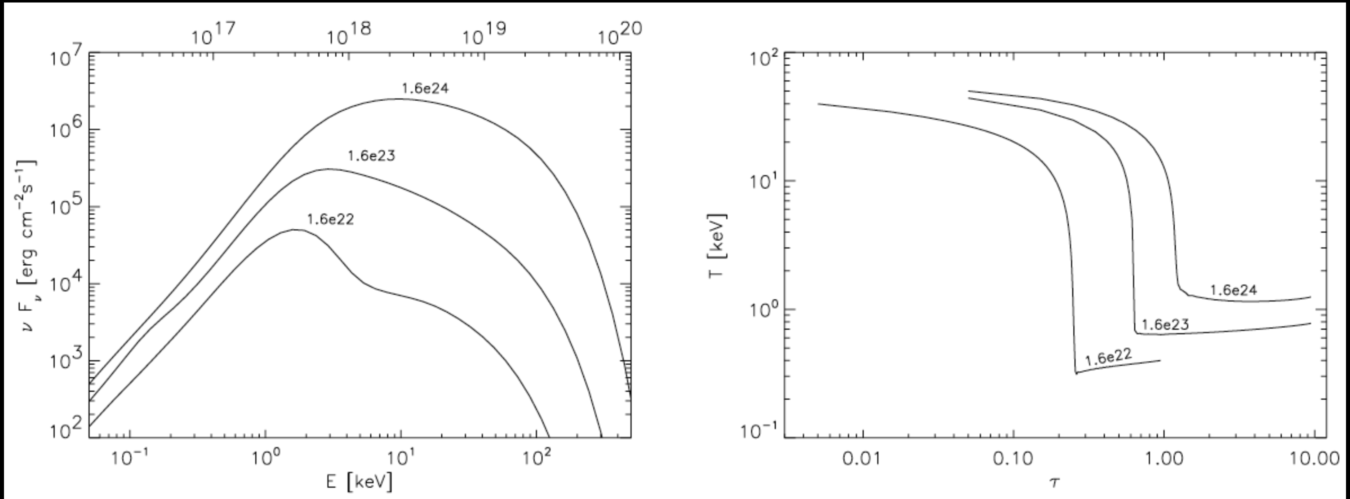
(Deufel et al. 2001)

Conclusions

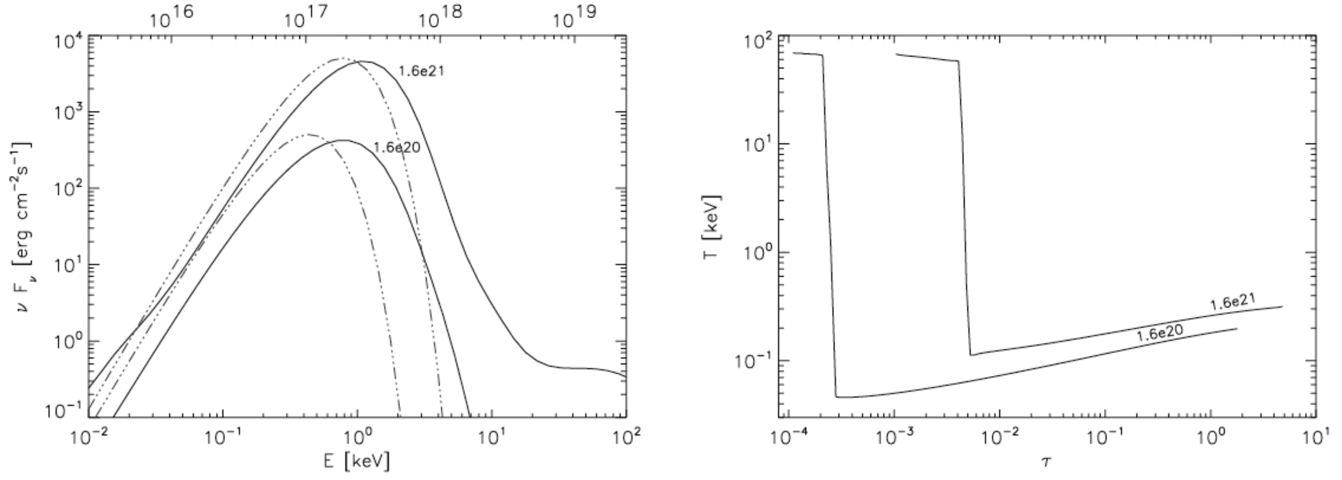


- Discovered third transient LMXB in Terzan 5; monitored during outburst.
- Quiescent counterpart looks like NS, X-ray burst confirms NS nature.
- Observed spectral hardening during a NS LMXB outburst rise for first time.
- This proves thermal component at Lx~1e35 from accretion, not crustal cooling.
- Hardening due to relative weakening of thermal component;
  Agrees with spectral modeling of NSs accreting at low rates.

Supplementary



High accretion rate



Low accretion rate

(Deufel et al. 2001)

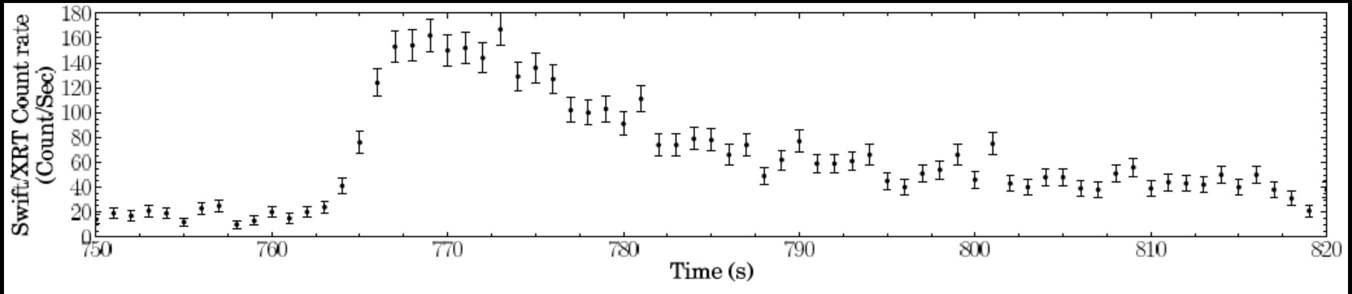
Spectral evolution: Rise

- Due to the relative reduction in strength of a thermal component.

Obs. ID	MJD	kT (keV)	$F_{X,BB}$ (0.5-10 keV) (10^{-12} erg s^{-1} cm^{-2})	$F_{X,PL}$ (0.5-10 keV) (10^{-12} erg s^{-1} cm^{-2})	$F_{X,PL}/F_{X,total}$	$L_{X,total}$(0.5-10 keV) (10^{34} erg s^{-1})	χ^2_ν/D.O.F
91445006	56114.8	0.31±0.03	5±2	5±2	50±20%	4±1	0.53/6
32148003	56115.8	0.36±0.03	9±3	13±4	59^{+15}_{-16}%	9±2	0.68/5
32148004	56117	0.41±0.02	15^{+4}_{-3}	17±6	53^{+12}_{-16}%	13±3	1.19/9
32148005	56118.1	$0.44^{+0.05}_{-0.07}$	20±10	70±20	78^{+12}_{-15}%	37±9	0.55/6
32148006	56120.7	0.67±0.06	110±40	500^{+60}_{-70}	82^{+7}_{-8}%	250±30	1.39/19

Thermonuclear burst

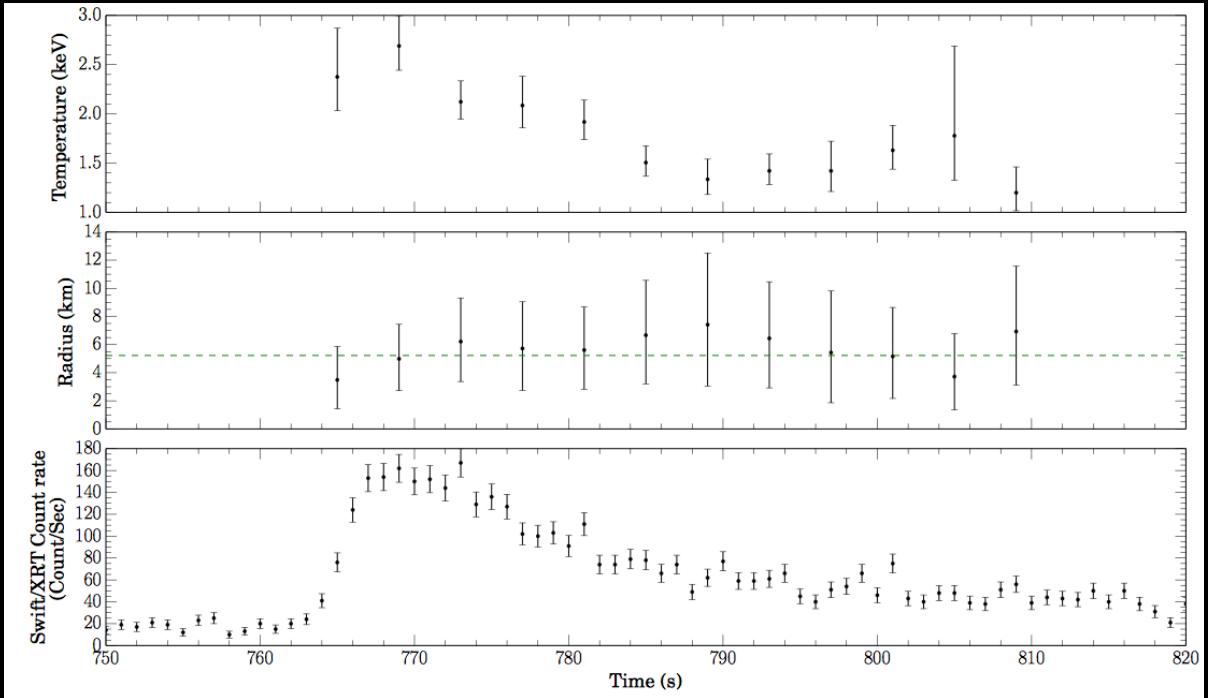
- Absorbed blackbody used for spectral analysis
- Burst timescale ~ 29 s (following Galloway et al. 2008)
- No photospheric radius expansion detected
- Long (>10 s) timescale suggests hydrogen burning
- Orbital period > 1.5 hours



Thermonuclear burst from Terzan 5 X-3

(Bahramian et al. 2014)

Thermonuclear burst: Spectral analysis



Rapid cooling can be seen during the burst.