The Long Term Analysis of GS 1826-24 using StrayCats

The Sudden Spectral State Transition of a Clocked Burster

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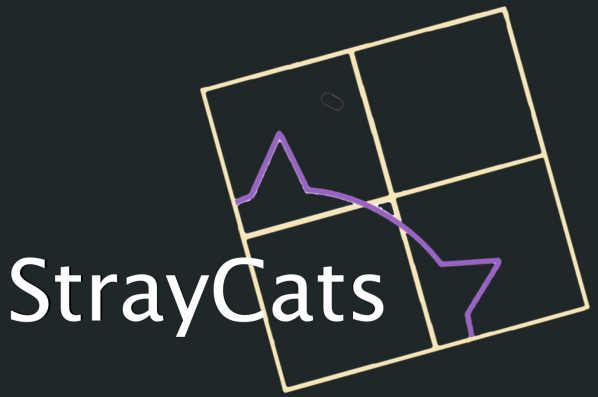

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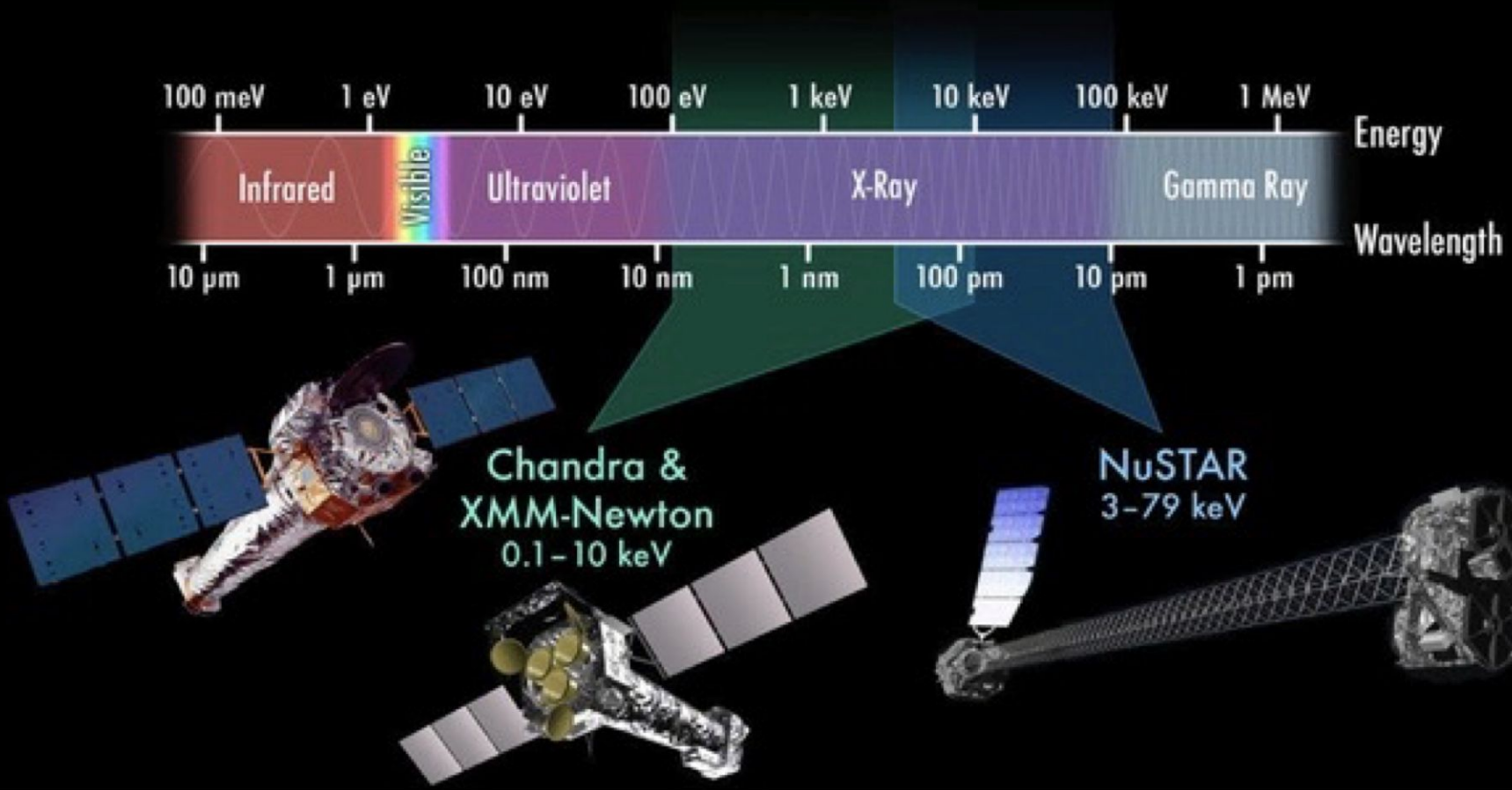
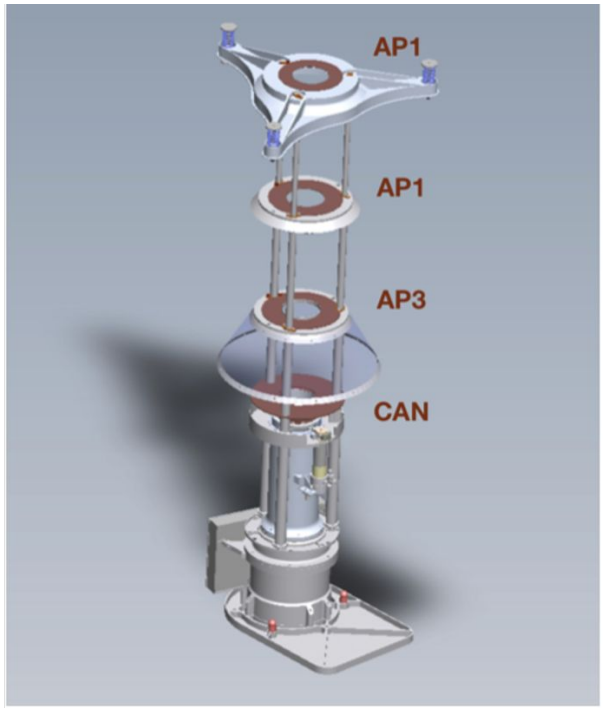
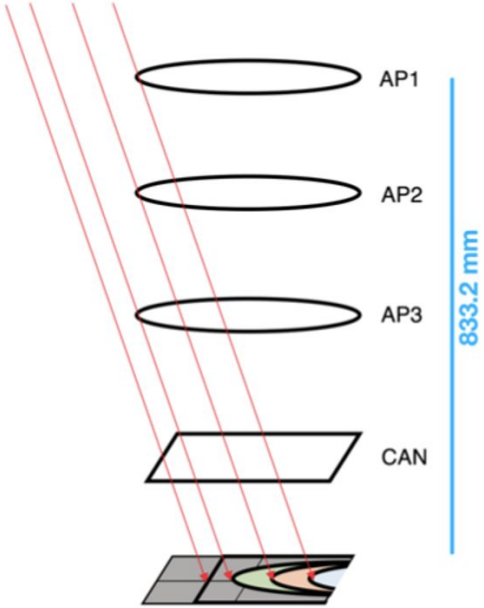


What is Stray Light?

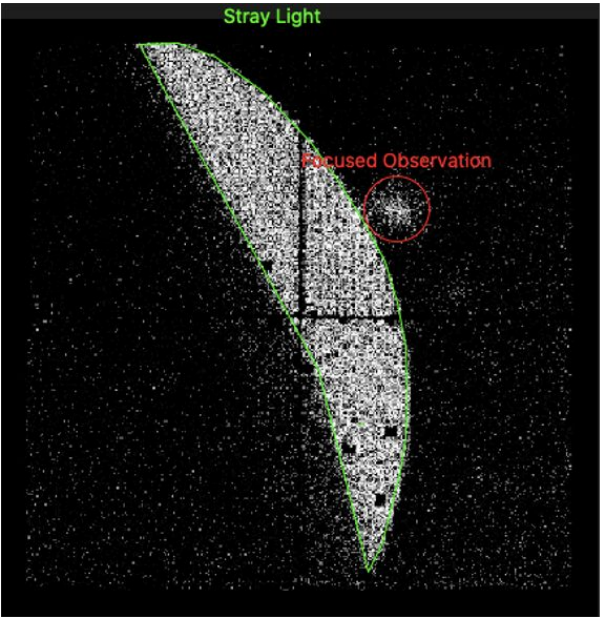


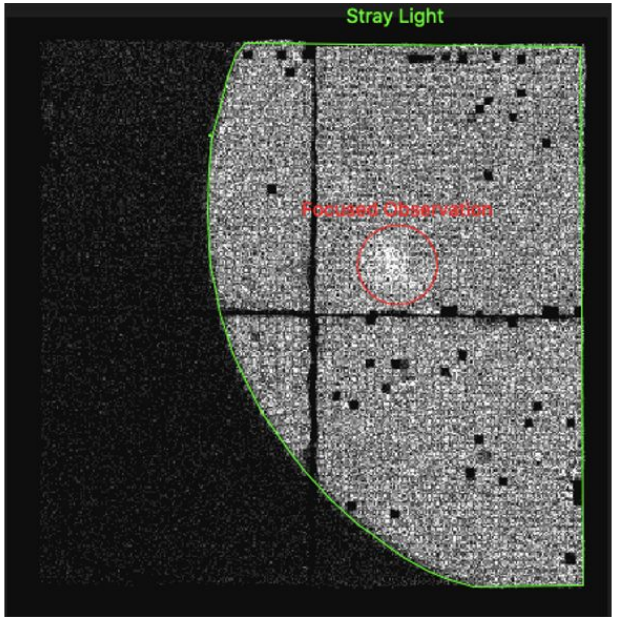


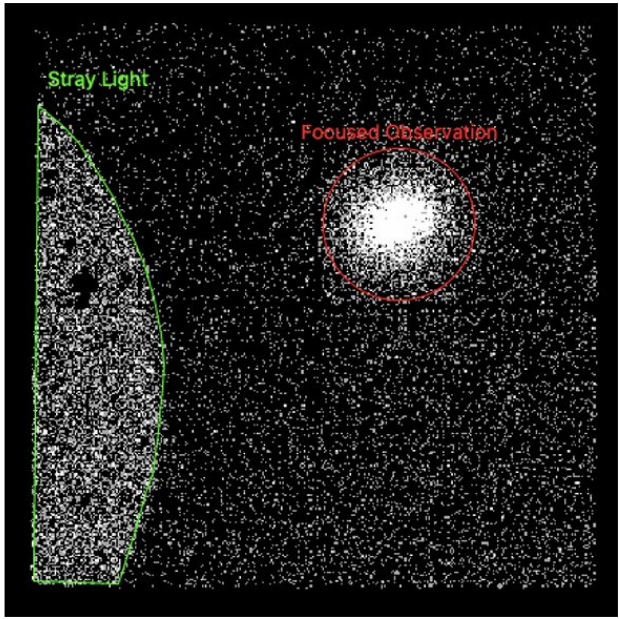
- Light that has not been focused by the NuSTAR optics
- Open geometry of mast (left) connecting optics to detectors allows possibility of stray light illuminating detectors (right)

Madison et al. (2017)

What is Stray Light?







- Stray light from single off-axis source creates a shadow on the Field of View
- NuSTAR observations of targets near Galactic plane contaminated by stray light from large X-Ray binaries nearby

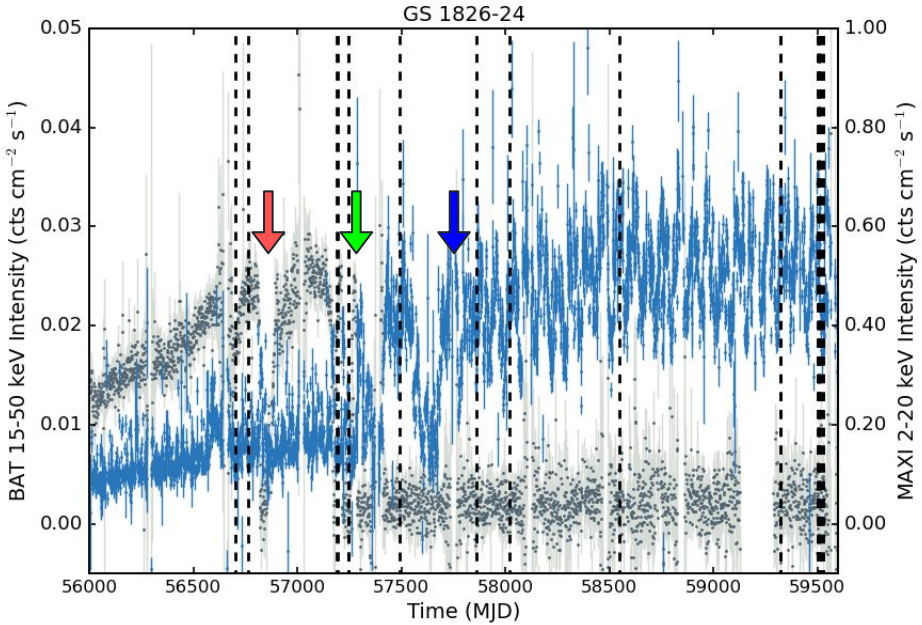
Why use Stray Light Data?

- Serendipitous observation of sources
- Track sources for longer periods of time
    - At an improved sensitivity compared to other All-Sky X-Ray Monitors
- Increase our knowledge of the long term behaviour of individual X-Ray sources

GS 1826-24: A Clocked Burster

- Low Mass X-Ray Binary
  - Neutron Star Binary System
  - Atoll source
- Clocked Burster
- Sudden soft state transition
  - First reported by Chenevez (2016)
  - Increase in low temperature flux;

    Drop out in high temperature emission



Long-term 2-20 keV MAXI lightcurve (blue); Swift-BAT transient monitor 15-50 keV lightcurve (grey); timing of Stray Light observations (dashed black lines), Grefenstette et al. (2022)

Stray Light Observations of GS 1826-24

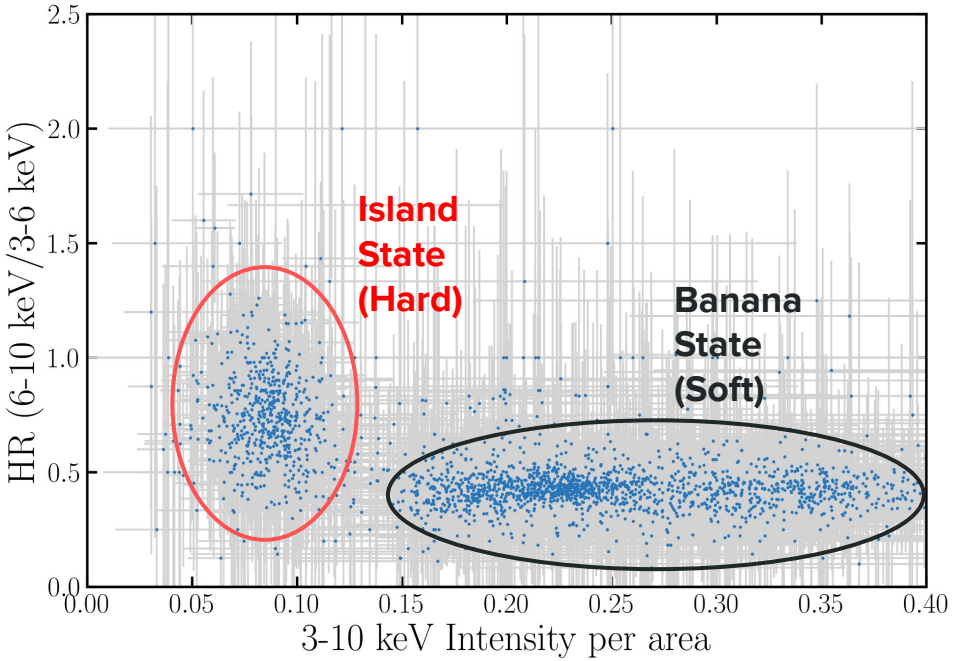
Obs #	Sequence ID	Time	MJD	FPM	Exposure (ks)	Area (cm^2)	# Type 1 Bursts
1	80002012002	2014-02-14T00:36:07	56702.0	A	24.05	1.84	2
2	80002012004	2014-04-17T22:46:07	56765.0	A	26.42	2.30	3
3	30101053002	2015-06-17T16:06:07	57190.7	A	131.3	2.71	14
4	30101053004	2015-06-21T07:11:07	57194.3	A	51.52	2.56	3
5A	90102011002	2015-08-14T12:21:08	57248.5	A	30.65	1.77	3
5B	-	-	-	B	30.60	3.39	2
6	60160692002	2016-04-14T18:26:08	57492.8	B	21.78	1.66	0
7	10202005002	2017-04-18T13:06:09	57861.6	A	156.5	2.38	4
8	10202005004	2017-09-23T08:36:09	58019.4	B	155.3	8.71	2
9	80460628002	2019-03-08T20:21:09	58550.9	B	41.05	1.65	0
10A*	90701314002	2021-04-20T11:16:09	59324.5	A	36.28	0.20	0
10B*	90701314002	-	-	B	36.28	0.13	0
11A	80702324002	2021-10-15T11:01:09	59502.5	A	18.04	1.28	0
11B	-	-	-	B	17.97	1.38	0
12A	80702324004	2021-10-19T13:11:09	59506.6	A	19.16	1.66	0
12B	-	-	-	B	19.06	1.48	1
13A	80702324006	2021-10-22T08:46:09	59509.4	A	17.47	1.38	1
13B	-	-	-	B	17.39	1.30	1
14A	80702324008	2021-10-26T23:56:09	59514.0	A	19.95	1.74	0
14B	-	-	-	B	19.82	1.45	0
15A	80702324009	2021-11-09T12:51:09	59527.5	A	20.12	1.77	0
15B	-	-	-	B	20.00	1.46	0

NOTE—The set of Sequence IDs above the solid line are observations during the hard spectral state whereas those below the line are observations of the soft state. Observations marked with an asterisk (*) were not used in the analysis due to low Stray Light area.

HR Diagram

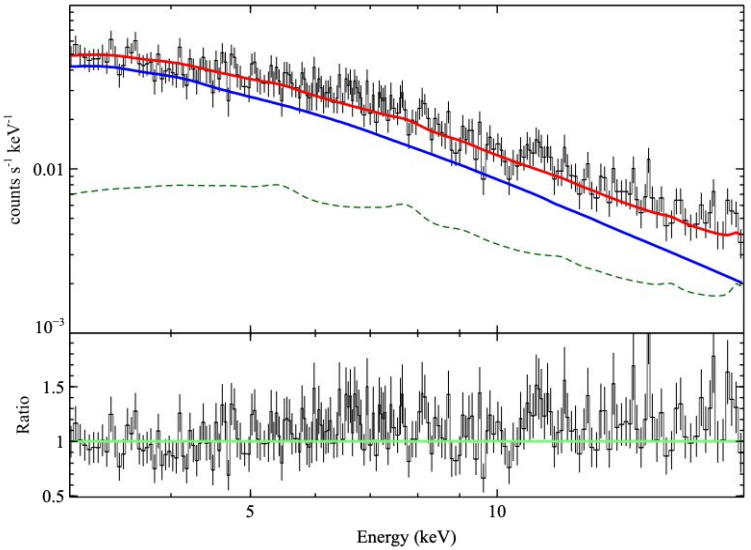
- Plotted using 500s lightcurves
- Ratio of 6 - 10 keV lightcurves against 3 - 6 keV lightcurves

Clearly demonstrates the two spectral states commonly seen in atoll sources:



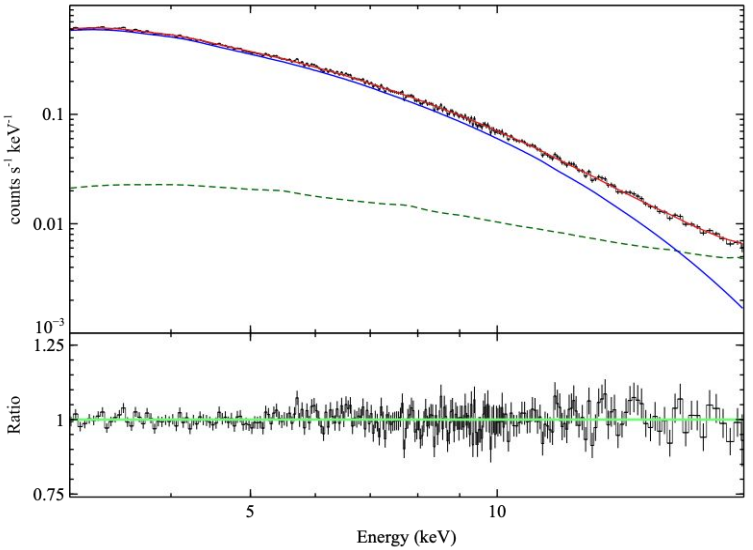
Spectral Fitting of Hard and Soft States

- XSPEC Model: tbabs * (cflux * compTT)
- “Representative spectra” chosen for each spectral state



← Hard State (Left)

Soft State → (Right)



Spectral Fitting of Hard and Soft States

Parameter	Hard State	Soft State
kT (keV)	33^{+21}_{-13}	$2.30^{+0.05}_{-0.02}$
T_0 (keV)	$0.11^{+0.07}_{-0.07}$	$0.49^{+0.02}_{-0.02}$
τ_p	$0.9^{+0.6}_{-0.4}$	$5.5^{+0.1}_{-0.1}$
Flux (10^{-9} erg s^{-1} cm^{-2})	$3.1^{+0.5}_{-0.6}$	$4.78^{+0.05}_{-0.04}$
Luminosity (10^{37} erg s^{-1})	$1.2^{+0.2}_{-0.2}$	$1.86^{+0.02}_{-0.02}$

*Bolometric Flux (0.001 - 1000 keV)

From hard to soft state:

- Significant drop in electron temperature (kT)
- Increase in seed photon temperature (T_0) and optical depth (τ_p)

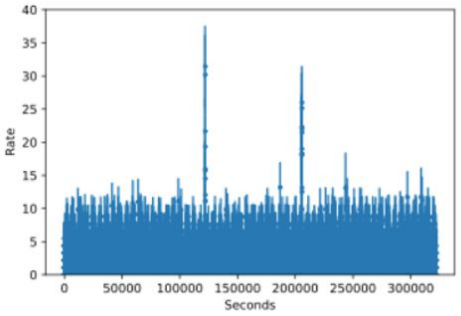
Increase in luminosity, but not very significant ➔ No significant change in mass accretion rate?

Type-1 X-Ray Bursts in GS 1826-24

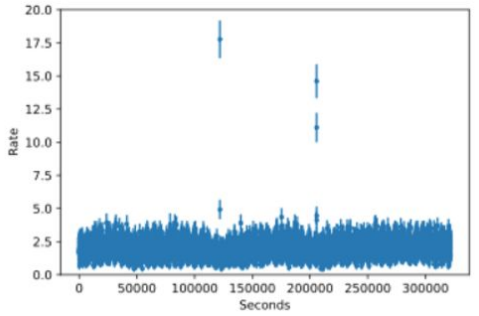
GS 1826-24 is a Clocked Burster

- 22 bursts recorded in Hard State
- 11 bursts recorded in Soft State

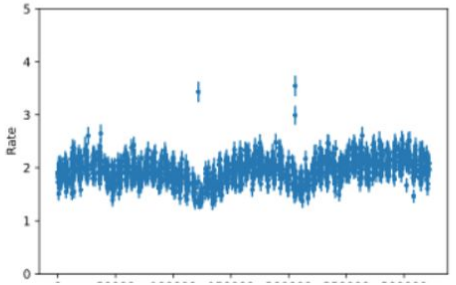
Speculation: Lower burst frequency (longer burst recurrence times) for soft state?

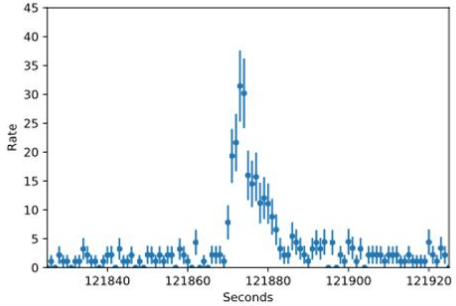


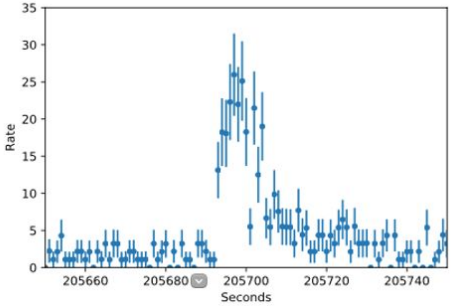
(a) Time bin: 1s



(b) Time bin: 10s

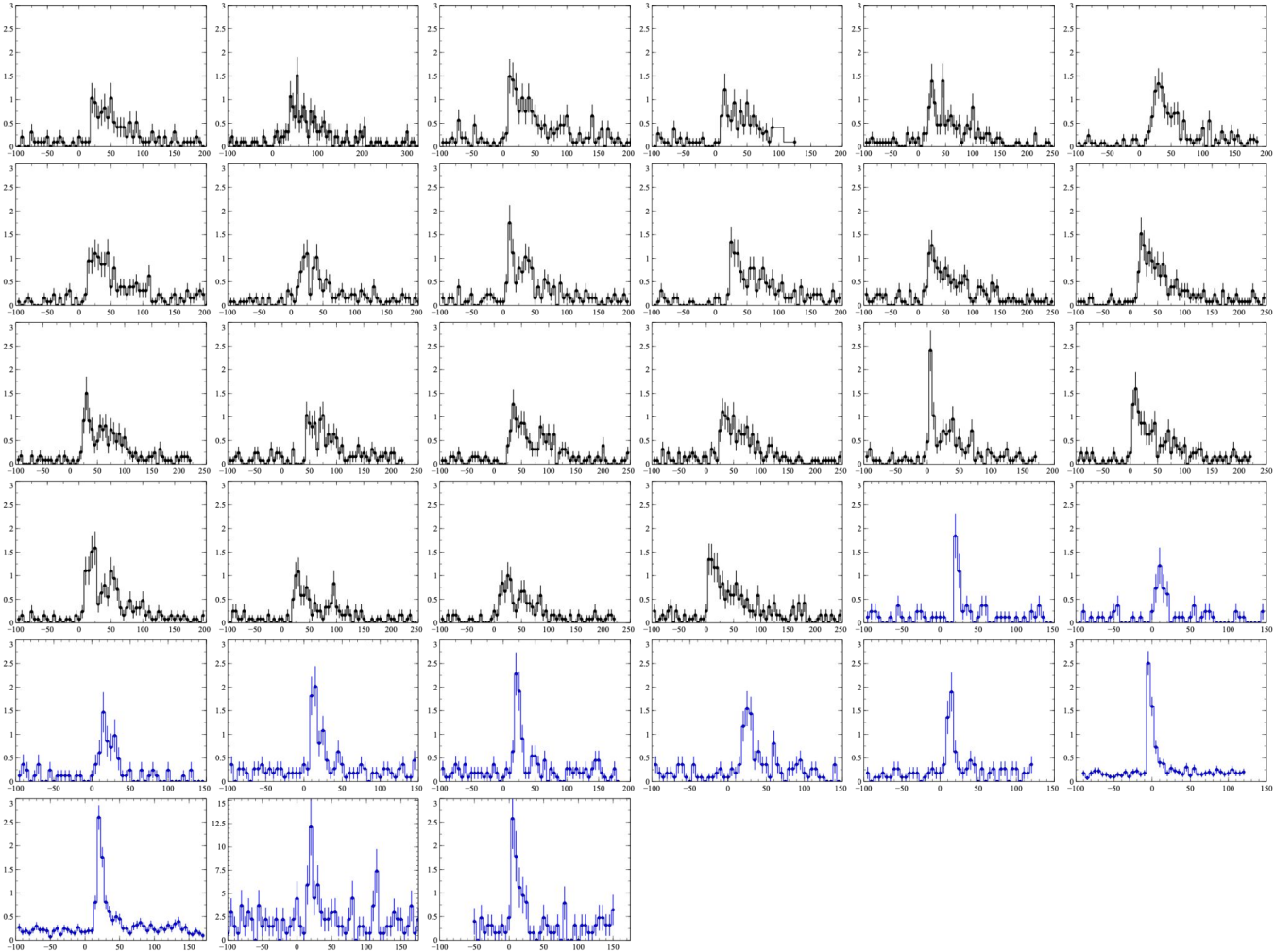






Rogues Gallery of Type-1 X-Ray Bursts

- 5s time bin
- Rate per area vs Time since burst onset
- Black: Hard State
- Blue: Soft State



Modelling the Type-1 X-Ray Bursts

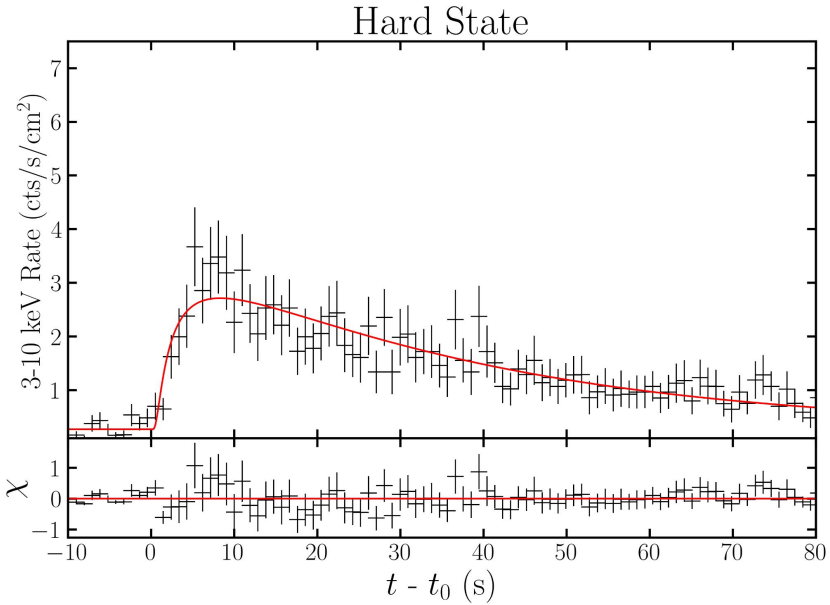
Fast Rise Exponential Decay (FRED) Model:

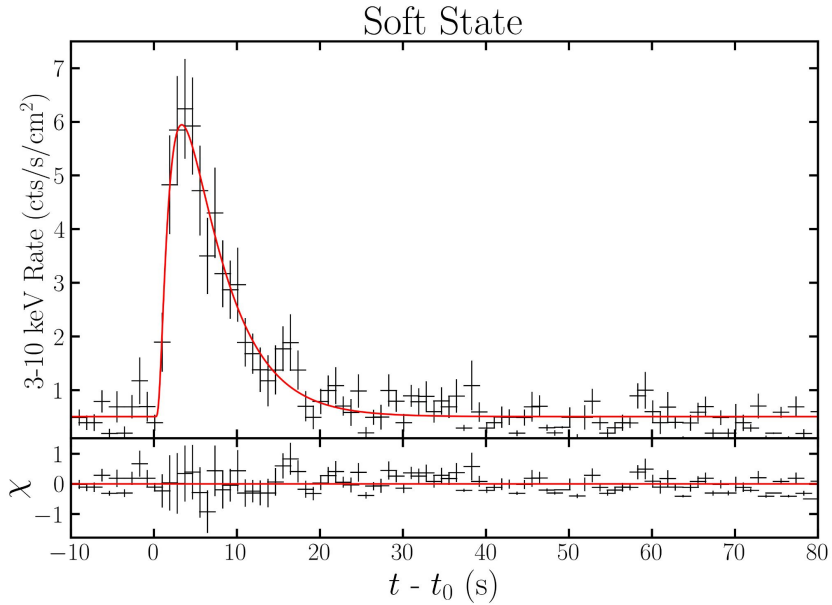
$$f(t) = A\, exp\left[-\frac{\tau_R}{t-t_0} - \frac{t-t_0}{\tau_D}\right]$$

Relatively low count rate of the burst lightcurves

- Stacking all the hard state bursts and all the soft state bursts
- FRED model was fit to stacked light curves at 1s time bins

Light Curve Fits





Light Curve Fit Results

Parameter	Hard State	Soft State
τ_R (s)	1.9 ± 0.3	2.5 ± 0.2
τ_D (s)	36 ± 3	4.6 ± 0.3
A (cts s^{-1} cm^{-2})	3.9 ± 0.2	24 ± 3
C (cts s^{-1} cm^{-2})	0.27 ± 0.06	0.51 ± 0.04
t_{peak} (s)	8.3 ± 1.1	3.3 ± 0.3
$t_{tail} - t_{peak}$ (s)	71.5 ± 1.1	10.4 ± 0.3
t_{90} (s)	$105.2^{+7.8}_{-8.3}$	$15.3^{+1.0}_{-0.9}$
Integrated Counts (cts cm^{-2})	$133.8^{+2.5}_{-2.7}$	$49.6^{+0.6}_{-0.4}$
Avg. Burst Rate (cts s^{-1} cm^{-2})	$1.27^{+0.13}_{-0.11}$	$3.24^{+0.25}_{-0.23}$

- t_{peak}: Time since burst onset to its peak intensity
- t_{tail}: Time since burst onset to 25% of its peak intensity
- t_{90}: Time between the 5th percentile and the 95th percentile of the cumulative counts of the burst

Physical Interpretation

As GS 1826-24 transitions to the soft state:

- From a hot and thin corona to a cold(er) and thick electron cloud
  - Increase in optical depth and decrease in electron temperature
- Optical depth increases and electron temperature cools
- Change in the Type-1 X-Ray Bursts
  - Frequent, Regular bursts (Hard) to Infrequent, Irregular bursts (Soft)
  - Type-1 Bursts in hard state are predominantly hydrogen

    Type-1 Bursts in soft state shows increased fraction of helium
- What caused the spectral state transition?

Future Plans

Focused observation of GS 1826-24

- More refined modelling of the persistent spectra
- Spectral Modelling of Type-1 Bursts if there’s any detected

Timing Analysis

Lightcurve Recurrence Times

Paper Writing!

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