The "Clocked Burster" GS 1826-24 acting out of character

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We report on *NuSTAR* and *Swift* first observations of a soft spectral state of the "clocked" burster, GS 1826−24. The state transition was revealed in 2014 June by an increase of the 2–20 keV source intensity measured by *MAXI*, simultaneous with a decrease of the 15–50 keV intensity measured by *Swift/BAT*. The episode lasted approximately two months, after which the source returned to its usual hard state. We analyse the broad-band persistent spectrum measured by *Swift/XRT* and *NuSTAR*, and estimate the accretion rate during the soft episode to be about 13% $\dot{m}_{\rm Edd}$, that is within the range of previous observations. However, the best fit spectral model, adopting the double Comptonization used previously, exhibits significantly softer components. We detect seven type-I (thermonuclear) X-ray bursts, all significantly weaker (and with shorter rise and decay times) than observed previously. The burst profiles and recurrence times vary significantly, and we rule out at high confidence the regular bursts that are typical for this source. One burst exhibited photospheric radius expansion, and we estimate the source distance in kpc as $5.7\pm0.2\ \xi_b^{-1/2}$, where ξ_b parameterizes the possible anisotropy of the burst emission. Interpreting the soft state as a transition from an optically thin inner flow to an optically thick flow passing through a boundary layer, as is commonly observed from other neutron stars in low-mass X-ray binaries, is contradicted by the lower optical depth measured for the best-fit double-Comptonisation model. The effect of a change in disk geometry on the burst behaviour remains unclear.

X-ray bursters are a class of low-mass X-ray binaries where the accreted material undergoes unstable thermonuclear burning in the surface layers of a neutron star. Such type I X-ray bursts, characterised by a black-body emission with temperature, kT, between 1 and 3 keV, have typical duration of a few tens of seconds. They have a recurrence time of hours to days, which mainly depends on the accretion rate. Observations of X-ray bursts have made it possible to investigate the nuclear processing on the surface of neutron stars, leading to a better understanding of their inner thermal structure, magnetic field, and spin (see [1], for a review).

GS 1826−24 (aka Ginga 1826−238, as well as the "clocked" or "textbook" burster; see [2]) exhibits the closest agreement with theoretical model predictions among the over 100-known thermonuclear burst sources. It has exhibited regular bursting behaviour with highly consistent properties from burst to burst over the 30 years since its discovery as a new transient in 1988 by *Ginga* [3]. Since then, GS 1826−24 has consistently been observed in a characteristic hard persistent spectral state.

On 2014 June 8, GS 1826−24 was detected for the first time in a soft spectral state [4],which lasted more than two months, according to the long-term monitoring by *MAXI/GSC* and *Swift/BAT* instruments (see Fig. 1). Here we present analysis of *NuSTAR* and *Swift* target-of-opportunity (ToO) observations of GS 1826−24 triggered in response to this unprecedented episode.

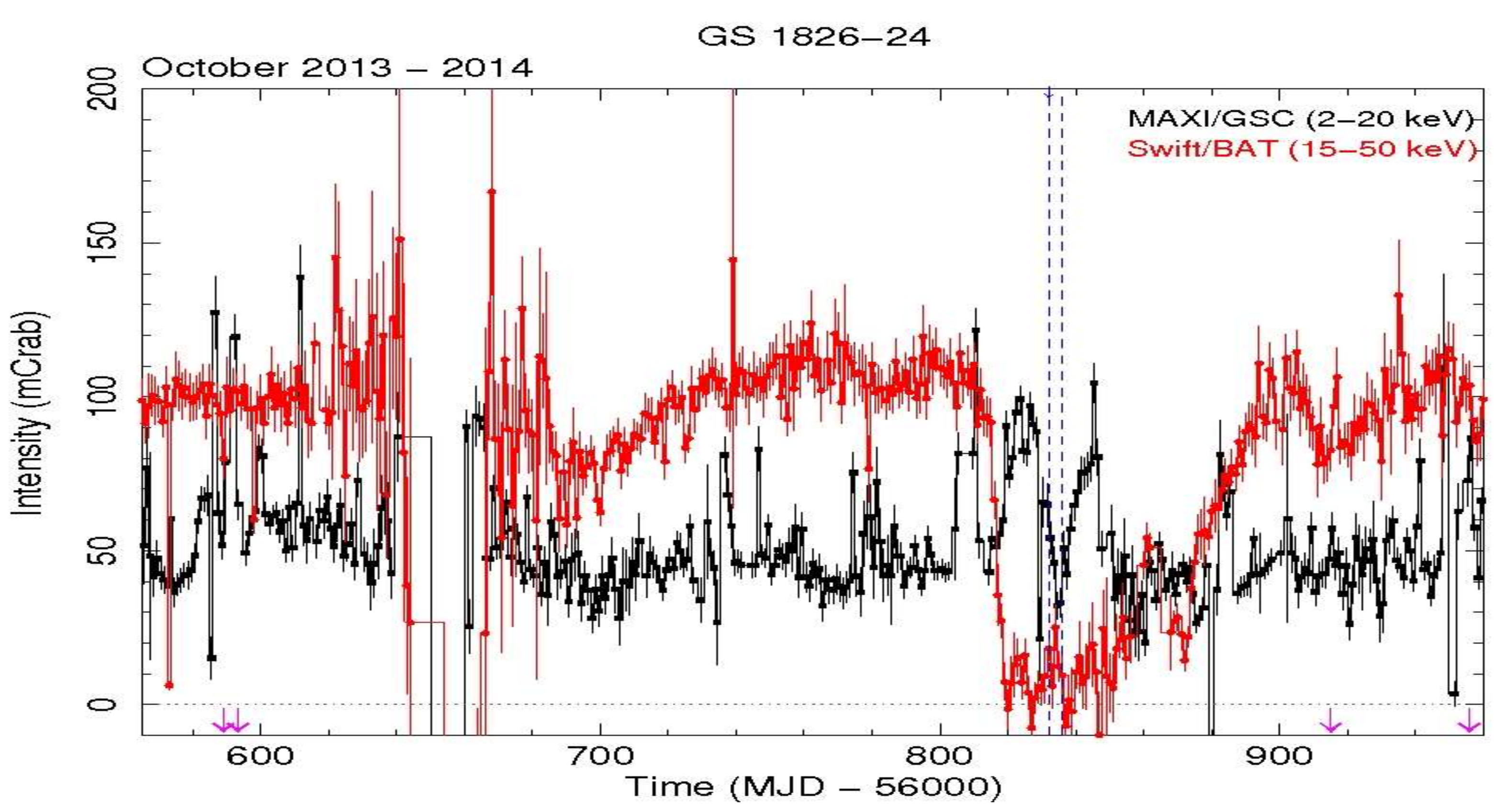

Fig.1 .— Daily averaged persistent intensity of GS 1826−24 between 2013 October 1 and 2014 October 30 as measured by *MAXI* and *Swift/BAT*. The instrument count-rates are converted into mCrab as 1 Crab (3.2×10^{-8} erg cm^{-2} s^{-1}) = 3.3 counts cm−2 s−1 for *MAXI* (2–20 keV) and 1 Crab (1.5×10^{-8} erg cm^{-2} s^{-1}) = 0.22 counts cm^{-2} s^{-1} for *BAT* (15–50 keV). The time interval approximately between MJD 56640 and 56665 corresponds to the time the source could not be observed due to the solar constraints of the instruments. The time interval of our *Swift* and *NuSTAR* observations is indicated by vertical dashed lines (MJD 56832 – 56836). Arrows on the time axis indicate the dates of bursts observed by *INTEGRAL/JEM-X*.

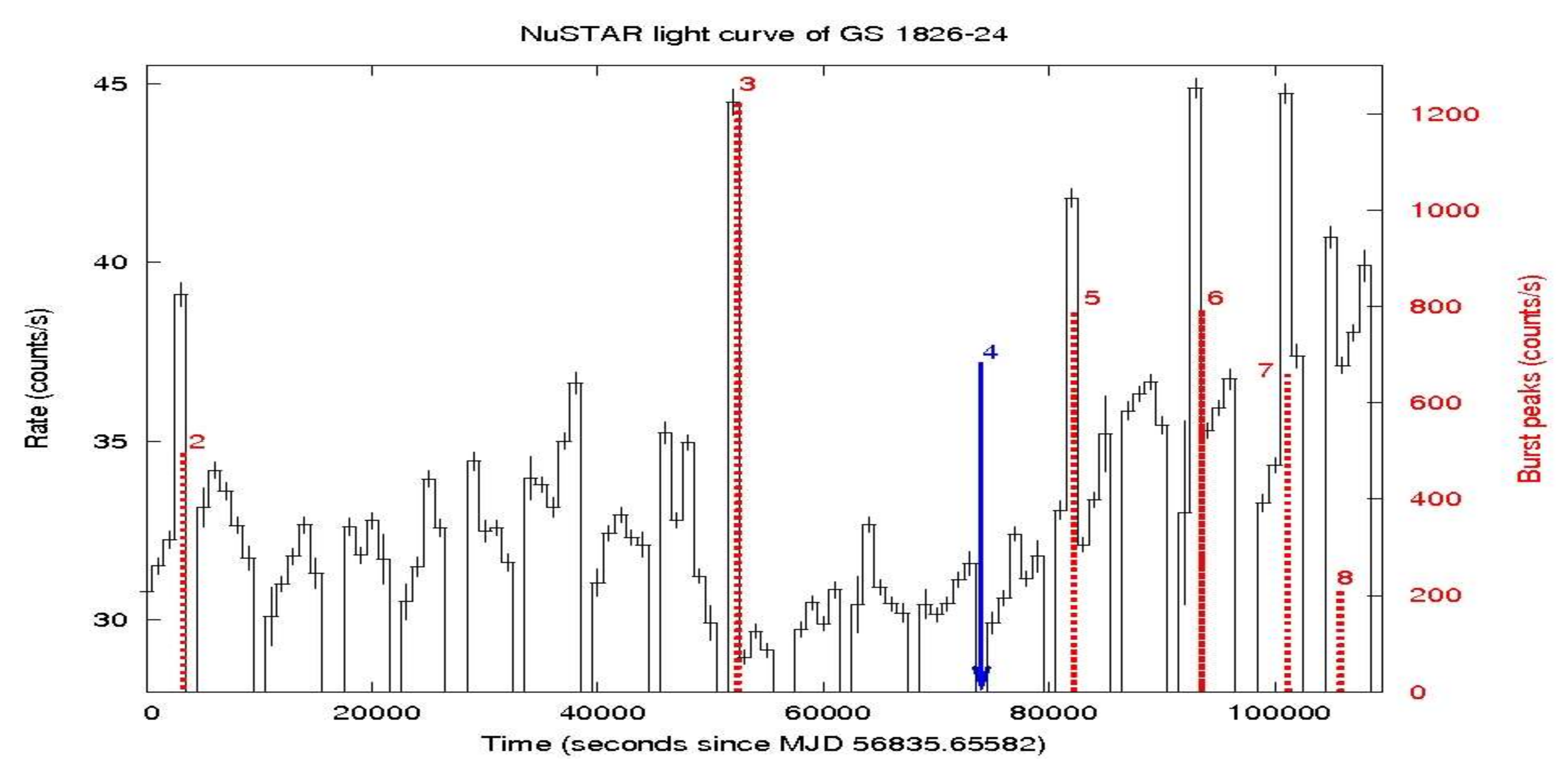

Fig. 2.— 3–42 keV X-ray intensity of GS 1826−24 measured by *NuSTAR/FPMA* during the 2014 June ToO. The persistent emission at a 1000 s resolution is plotted (black symbols, histogram, left-hand y-axis) along with the time and peak intensity of the bursts (dashed red lines; right-hand y-axis). The blue arrow indicates the time of a burst detected by *MAXI* during a data-gap of the *NuSTAR* observation.

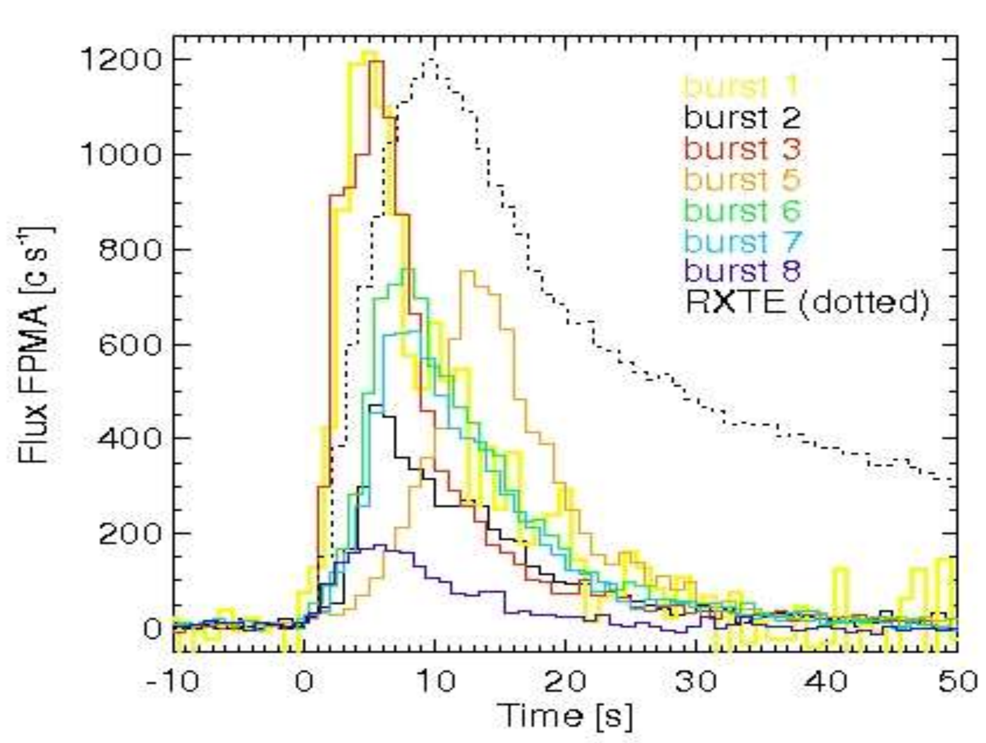

Fig. 3.— Light-curves of a first burst detected by *Swift* (#1; 0.2–10 keV) on June 24, and the six *NuSTAR* bursts (#2, 3, 5, 6, 7, 8; 3–42 keV) compared with a burst detected with *RXTE* (2–60 keV) on 1997 November 5. The pre-burst average count-rates are subtracted, and the *Swift* and *RXTE* burst peaks are normalized to the highest *NuSTAR* peak (burst 3) at about 1200 counts s^{-1}.

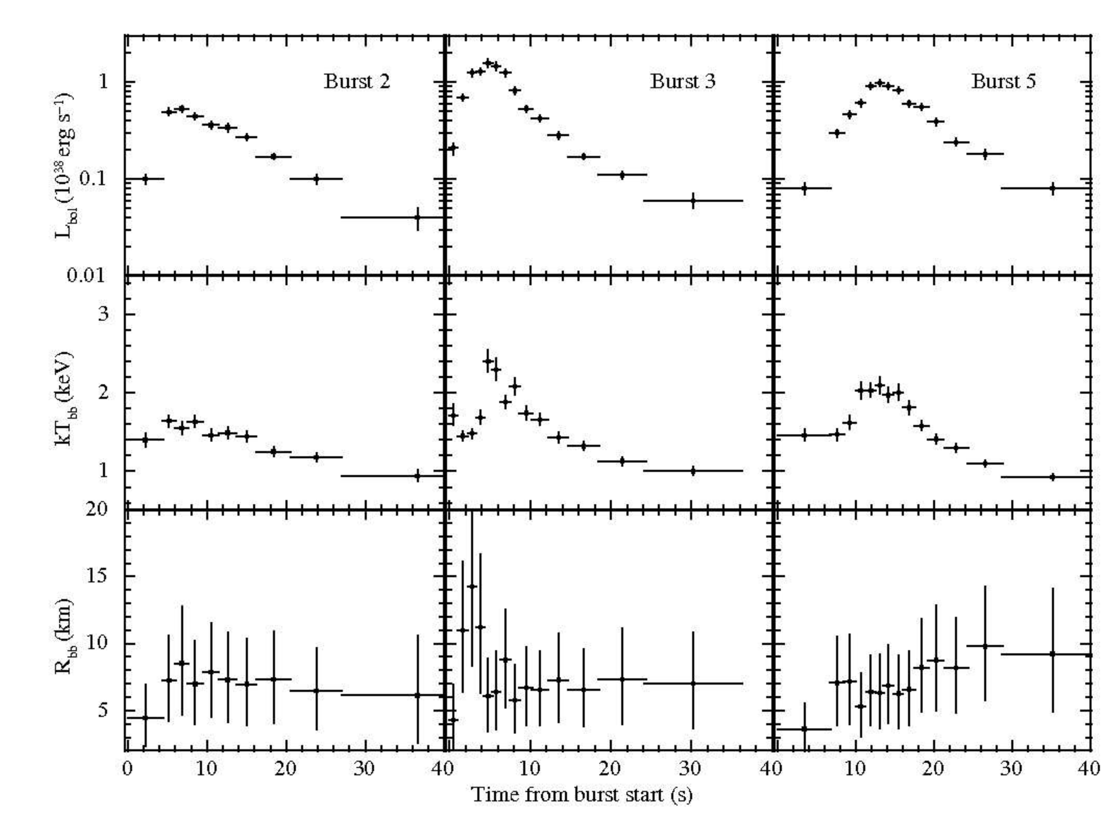

Fig. 4.— Time-resolved spectroscopy of *NuSTAR* bursts #2, 3, and 5. The top panel shows the inferred bolometric luminosity, assuming a distance of 5.7 kpc. The middle panel shows the best-fit blackbody temperature, and the lower panel shows the NS-radius. Burst #3 shows the characteristic evolution of a photospheric radius expansion with anti-correlated .T° and radius.

Burst no.	Instr.	Obs. ID	Start time (MJD)	Δt (hr)	Rise time[a] (s)	Timescale[a] (s)	Peak flux[b]	Fluence[c]	α[d]
1	*Swift*	00035342006	56832.99124	⋯	1.9 ± 0.3	11.3 ± 1.6	40^{+80}_{-20}	0.21 ± 0.08	⋯
2	*NuSTAR*	80001005002	56835.69484	64.89	2.4 ± 0.2	12.3 ± 1.1	13.8 ± 1.1	0.187 ± 0.006	⋯
3	*NuSTAR*	80001005003	56836.26299	13.636	1.13 ± 0.08	8.6 ± 0.6	40 ± 3	0.370 ± 0.009	337 ± 8
4	*MAXI*	⋯	56836.52240[e]	6.2 ± 0.3	⋯	⋯	⋯	⋯	⋯
5	*NuSTAR*	80001005003	56836.60928	2.1 ± 0.3	5.52 ± 0.19	11.8 ± 0.9	25.1 ± 1.9	0.335 ± 0.008	54 ± 8
6	*NuSTAR*	80001005003	56836.74176	3.179	3.35 ± 0.16	12.2 ± 0.9	27 ± 2	0.352 ± 0.009	86 ± 2
7	*NuSTAR*	80001005003	56836.82851	2.082	3.42 ± 0.17	12.6 ± 1.1	21.8 ± 1.6	0.280 ± 0.007	72.1 ± 1.8
8	*NuSTAR*	80001005003	56836.88213	1.287	3.4 ± 0.3	12.4 ± 1.4	6.6 ± 0.6	0.083 ± 0.005	156 ± 9

[a] Measured from the count-rate burst light curve in the relevant energy band

[b] Extrapolated peak bolometric flux in units of 10^{-9} erg cm^{-2} s^{-1}

[c] Integrated burst bolometric fluence in units of 10^{-6} erg cm^{-2}

[d] As every burst interval was interrupted by at least one data gap, the α-values must formally be considered upper limits

[e] This burst is recorded from the public *MAXI* orbital light curve, thus only its approximate time is available

Properties of the detected thermonuclear bursts from GS 1826-24 in June 2014.

The 2014 June soft spectral state of GS 1826−24 was the first ever recorded for this well-studied source, and it revealed a number of new observational aspects, including the first burst exhibiting photospheric radius expansion from which we infer a distance of as $5.7\pm0.2\ \xi_b^{-1/2}$, kpc , as well as weak, irregular bursting behaviour, including the shortest burst interval (1.29 hr) measured to date.

Our study of burst energetics shows that the ignition columns are consistently lower than the accreted column, so we conclude that GS 1826−24 was bursting inefficiently in the soft state, igniting fuel with significantly lower hydrogen fractions than the previously inferred solar value.

The results of our spectral analysis of the persistent emission compared to previous observations indicate a softening, but at a similar inferred accretion rate.

References

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[4] Nakahira et al., 2014, ATel 6250

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