Thermonuclear Burst Studies With Large Burst Samples

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Abstract

Some types of thermonuclear burst behavior are not amenable to study via observations of individual sources, typically because they occur rarely and/or unpredictably. A more promising approach lies in combining data from multiple sources. To date, many thousands of bursts have been detected by various instruments, and new observations are continually adding to the available data. I will describe the results from one such study, involving all the public observations to date made by the Rossi X-ray Timing Explorer (*RXTE*), presently totalling 1185 bursts from 48 sources. The capabilities of the Proportional Counter Array onboard *RXTE* enable detailed studies of photospheric radius-expansion, weak bursts (including short recurrence time bursts) and burst oscillations. The two most prolific bursters in the sample exhibit distinctly different bursting properties, suggesting different accreted compositions in the accreted fuel, and highlighting the diversity in burst behaviour which must be considered when combining burst samples. Large burst samples can also be used to measure the global variation of burst properties as a function of accretion rate, to compare with theoretical models. I will also describe a successor project, the Multi-Instrument Burst ARchive (MINBAR), which aims to collate all bursts observed by modern instruments to enable comprehensive future studies of rare events and broad-scale behavior.

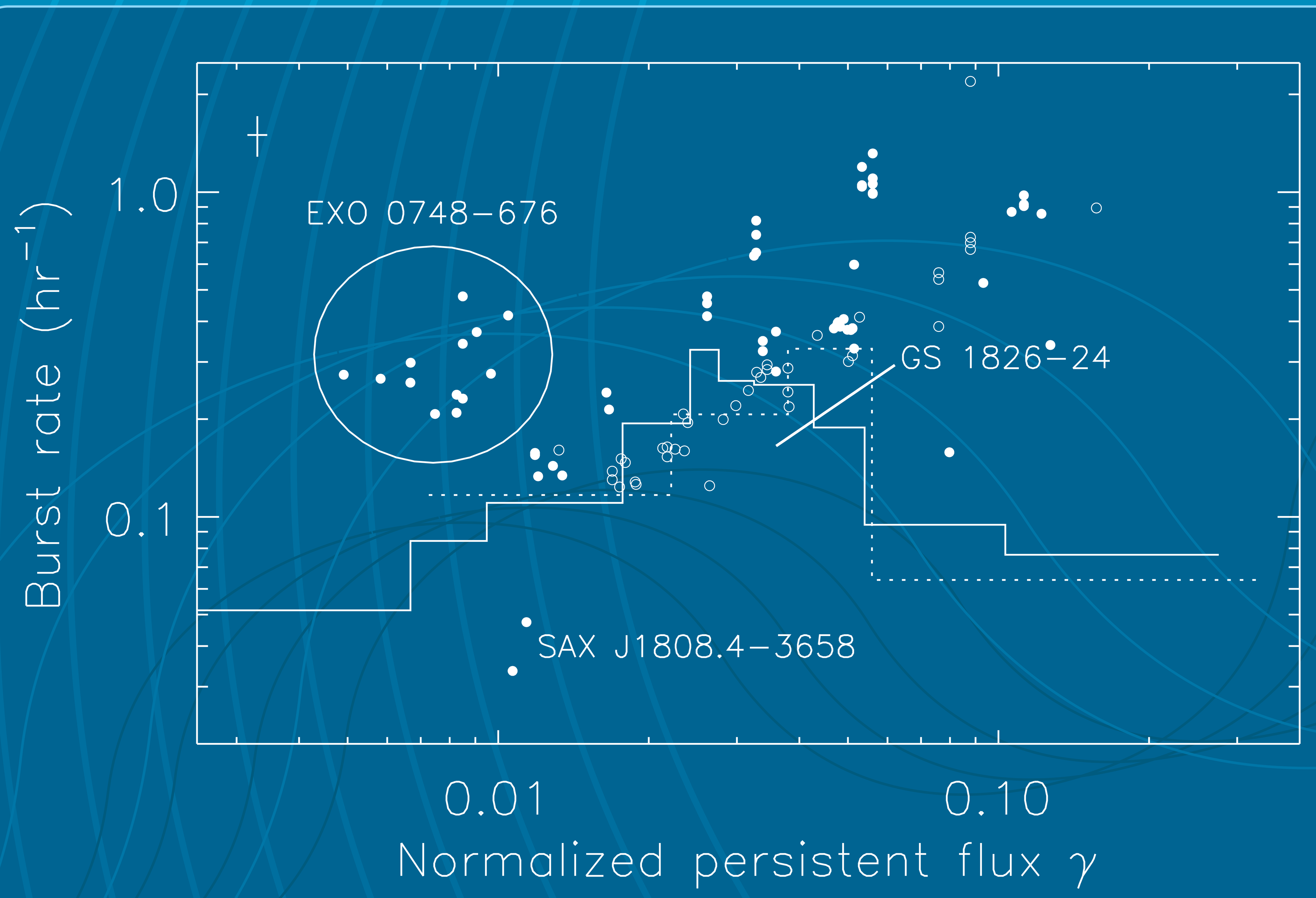

Figure 1.

Burst rates as a function of normalized persistent flux $\gamma = F_x/F_{Edd}$ from the two groups of burst sources identified from the *RXTE* sample. The mean rates for systems with evidence of mixed H/He accretion are plotted as a solid histogram; bursts are combined in groups of ~50 for binning, and a typical error bar is shown at the top left. The mean burst rates for systems with consistently fast bursts (i.e. candidate He-accretors) are shown as the dashed histogram. Burst rates for pairs of sequential bursts are also shown (filled/open circles, for mixed H/He and pure He-accretors, respectively). While the variation of the burst rates with γ for the two groups is similar, both the variation with position on the color-color diagram, and the α-values, are not. Individual bursts from EXO 0748-676 and SAX J1808.4-3658 are representative of ignition cases 3 and 2 (e.g. Fujimoto et al. 1981) respectively, while the solid line labelled GS 1826-24 shows the flux-recurrence time relation derived for the case 1 ignition bursts from that source (Galloway et al. 2004).

Global burst behavior

While previous studies have indicated that the burst behavior of different sources is largely the same (e.g. Cornelisse et al. 2003), the RXTE sample reveals important differences. We combined the data from different sources by normalising the persistent flux by the mean peak flux of the radius-expansion bursts, F_{Edd}. The two most prolific bursters exhibit qualitatively different burst behavior as a function of accretion rate:

> 4U 1636-536 shows both short and long bursts (the latter characteristic of H-rich fuel) at low accretion rate, and largely short bursts at high accretion rate.

> 4U 1728-34, on the other hand, shows consistently short bursts indicative of largely-He fuel over the same range of accretion rate.

> We suggest the difference between these two sources arises from the lack of accreted hydrogen in 4U 1728-34; a number of other systems also show consistently short bursts, including known and candidate ultracompacts (see also poster 10.23).

We divided the burst sources up into systems with and without evidence of hydrogen in the accreted fuel, for studies of the rates and energetics (Figure 1).

The other strengths of the RXTE sample are in studies of weak bursts and high time-resolution behavior.

Short-recurrence Time Bursts

RXTE has good sensitivity for weak bursts, in particular those occurring episodically with short (<30 min) recurrence times

> Such bursts tend to arise in systems inferred to accrete mixed H/He, and are frequently associated with bursts arising from unstable hydrogen ignition (i.e. case 1 of Fujimoto et al. 1981)

> Burst triplets were observed from 4U 1705-44, the Rapid Burster, 4U 1636-536, 2E 1742.9-2929, EXO 1745-248 and 4U 1608-52; a quadruplet was also observed from 4U 1636-536

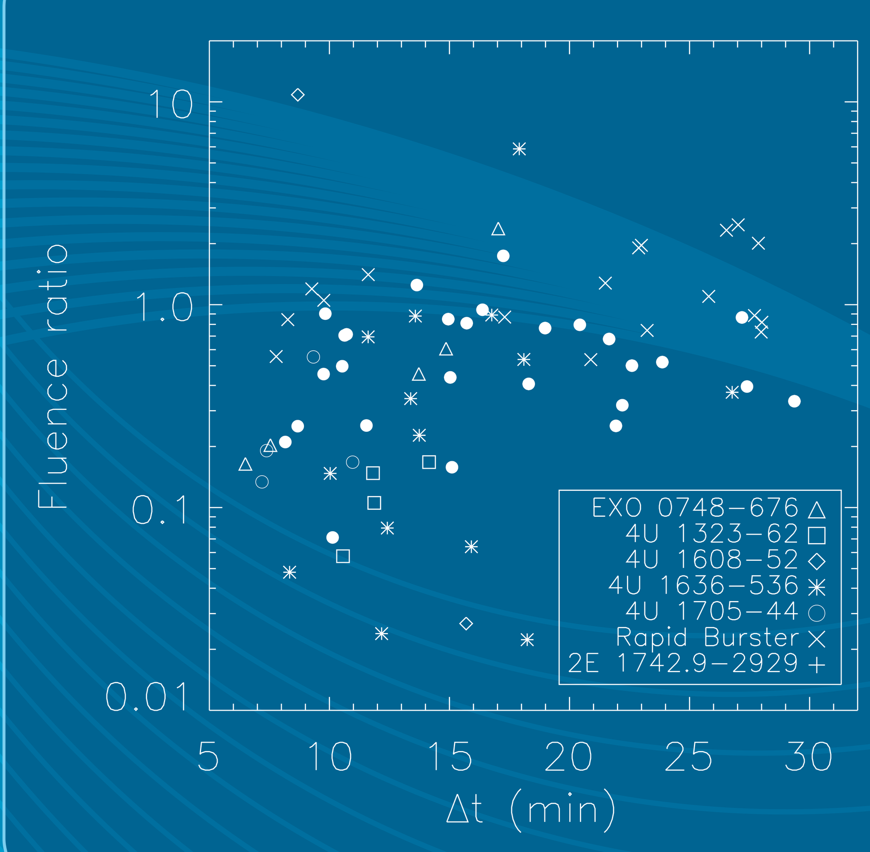

Figure 2.

Ratio of fluences (second/first) for pairs of bursts, plotted as a function of their separation. Several sources are plotted with different symbols; the remaining measurements come from XTE J1710-281 (1),4U 1735-44 (1), EXO 1745-248 (2), 4U 1746-37 (5), Aql X-1 (6) and Cyg X-2 (3) (filled circles)

Millisecond oscillations

We searched all the bursts from known burst oscillation sources for oscillations and examined where in the bursts they occurred

> Oscillations are most often detected in the burst tails (75%), and approximately equally likely (~55%) in the rise and peak. Oscillations were found both in short and long bursts

> We confirm the tendency for oscillations to be interrupted during most, but not all, radius-expansion bursts

The neutron star spin frequency has previously been shown to be related to the type of burst in which oscillations are most frequently detected (e.g. Muno et al. 2004). Sources with fast (>400 Hz) spin frequencies preferentially exhibit oscillations in radius-expansion bursts, while slow (<400 Hz) systems exhibit no significant preference.

We found that the slow sources (including 4U 1916-053, 4U 1702-429, 4U 1728-34) are largely also those systems for which we detect consistently fast bursts

This result suggests that the donor composition (and hence evolutionary history) may influence the neutron-star spin, or alternatively that spin-mediated shear significantly affects the burst properties (e.g. Piro & Bildsten 2007).

A distinct regime of nuclear burning

The RXTE sample indicates that the drop in burst rate observed in many sources at luminosities of $\sim 10^{37}$ erg/s is likely related to the well-known persistent spectral transition between the "island" and "banana" states

> Sources at this flux level are increasingly found in the "banana" state, where the bursts tend to be short and infrequent, and with large α-values

> Also detected at this spectral transition are mHz oscillations (Revnivtsev et al. 2001), perhaps arising from marginally stable He-burning (e.g. Heger et al. 2007).

> This drop in burst rate is also seen for the sources inferred to accrete hydrogen-poor material (e.g. Fig. 1).

Stable He-burning may explain some of the observational properties of bursts in the "banana" spectral state; alternatively, these bursts may be the "delayed mixed" bursts of Narayan & Heyl 2003

Extending the *RXTE* sample with MINBAR

Other instruments, particularly *BeppoSAX*/WFC and *INTEGRAL*/JEM-X have complementary strengths to *RXTE*, with lower sensitivity but greater coverage. These strengths are particularly suited to rare events such as superbursts and intermediate-duration bursts.

> Work is currently underway to combine the data from these instruments with the *RXTE* sample in order to provide an unprecedented sample of bursts for future studies

> The latest draft of this sample, the Multi-INstrument Burst ARchive (MINBAR), includes 3372 events observed by *RXTE* and the WFC from most of the known thermonuclear burst sources

> Future work will include adding the public bursts observed by JEM-X, and possibly other instruments; as with the *RXTE* catalog, the sample will be released publicly once complete

References

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