Constraining the properties of type-I (thermonuclear) X-ray burst systems

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Thermonuclear (type-I) X-ray bursts arise from unstable ignition of accreted fuel on the surface of neutron stars in low-mass binary systems. It is usually assumed that most systems accrete material with roughly solar composition, unless the orbital period is $\lesssim 80$ min, indicating an "ultracompact" system with a hydrogen deficient donor. However, few constraints on the donor composition are available.

Here we apply a Bayesian model-comparison framework, BEANSP, to the burst source and accretion-powered millisecond pulsar, IGR J17511–3057, to constrain the fuel composition as well as the system parameters. Although this system, with an orbital period of 3.5 hr can accommodate a H-rich donor, the burst properties and our analysis suggest an extremely hydrogen- and CNO-deficient fuel composition with X=0.04±0.01 and Z_{CNO}=(5.9±1.5)×10^{-4}. The implied distance is 13.4±1.1 kpc, and the neutron star is likely massive, ≈1.9 $M_{\odot}$.

We combine these results with the three other sources for which compositional constraints have been established, and find an unexpectedly wide range in compositions. This result may help to explain the remarkable diversity in burst properties of the sample of known bursters.

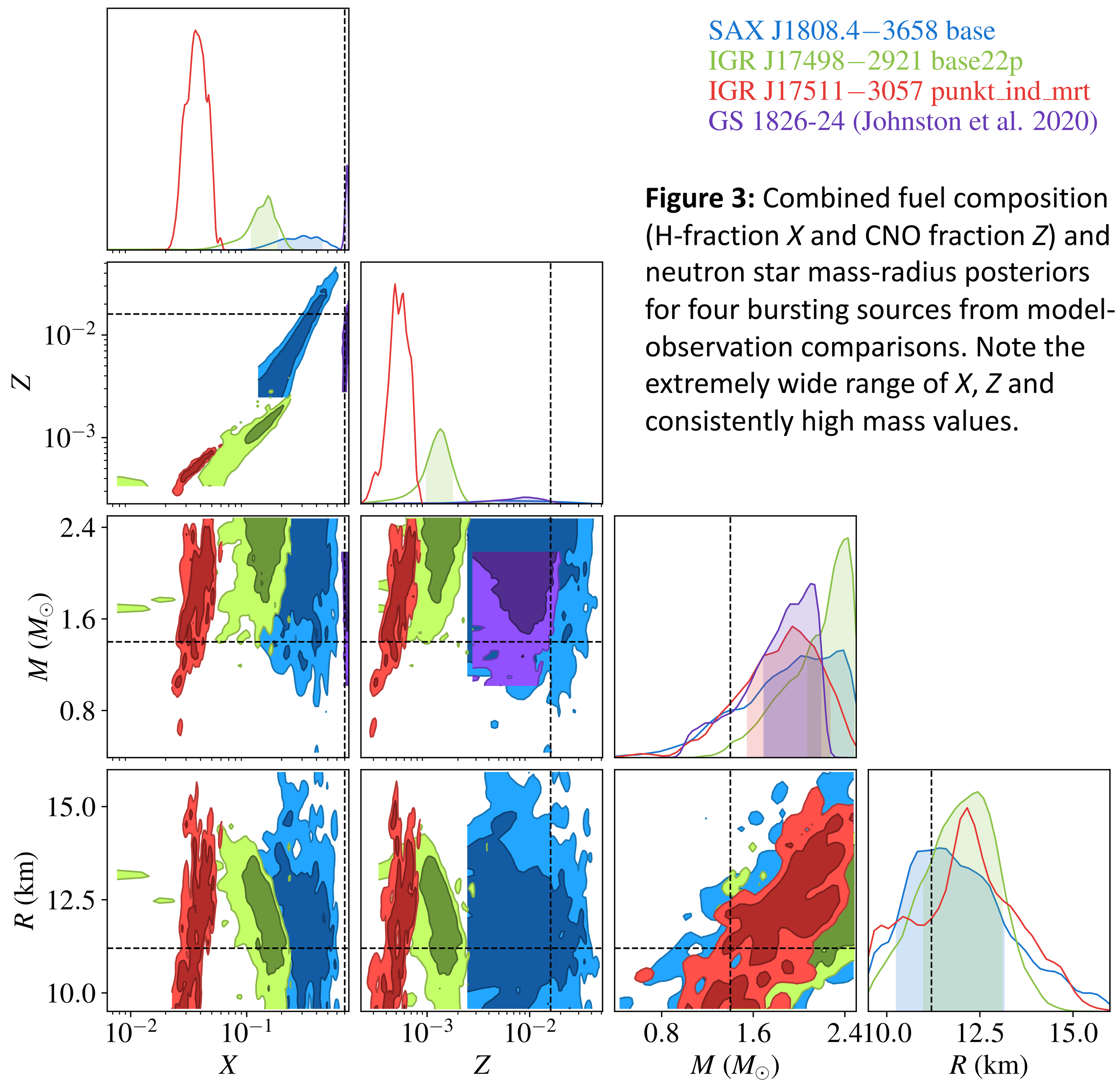

Figure 3: Combined fuel composition (H-fraction X and CNO fraction Z) and neutron star mass-radius posteriors for four bursting sources from model-observation comparisons. Note the extremely wide range of X, Z and consistently high mass values.

Matching models & data

We analysed a sample of 20 bursts observed during the 2010 outburst of IGR J17511–3057, detected with *RXTE*, *INTEGRAL* and *Swift* (Figure 1).

We corrected the burst fluences based on cross-instrument calibrations for events observed with multiple instruments simultaneously.

We used the BEANSP [1,2] code to generate sequences of bursts via the PySETTLE ignition code, and matched the predictions to observations, via MCMC chains to estimate the posterior distributions for model parameters.

As the largest burst sample attempted for such a match, this effort required many improvements and adjustments to the matching algorithm, including allowing gaps between widely-spaced pairs of bursts, simulating each burst independently, and allowing a systematic contribution to the burst times.

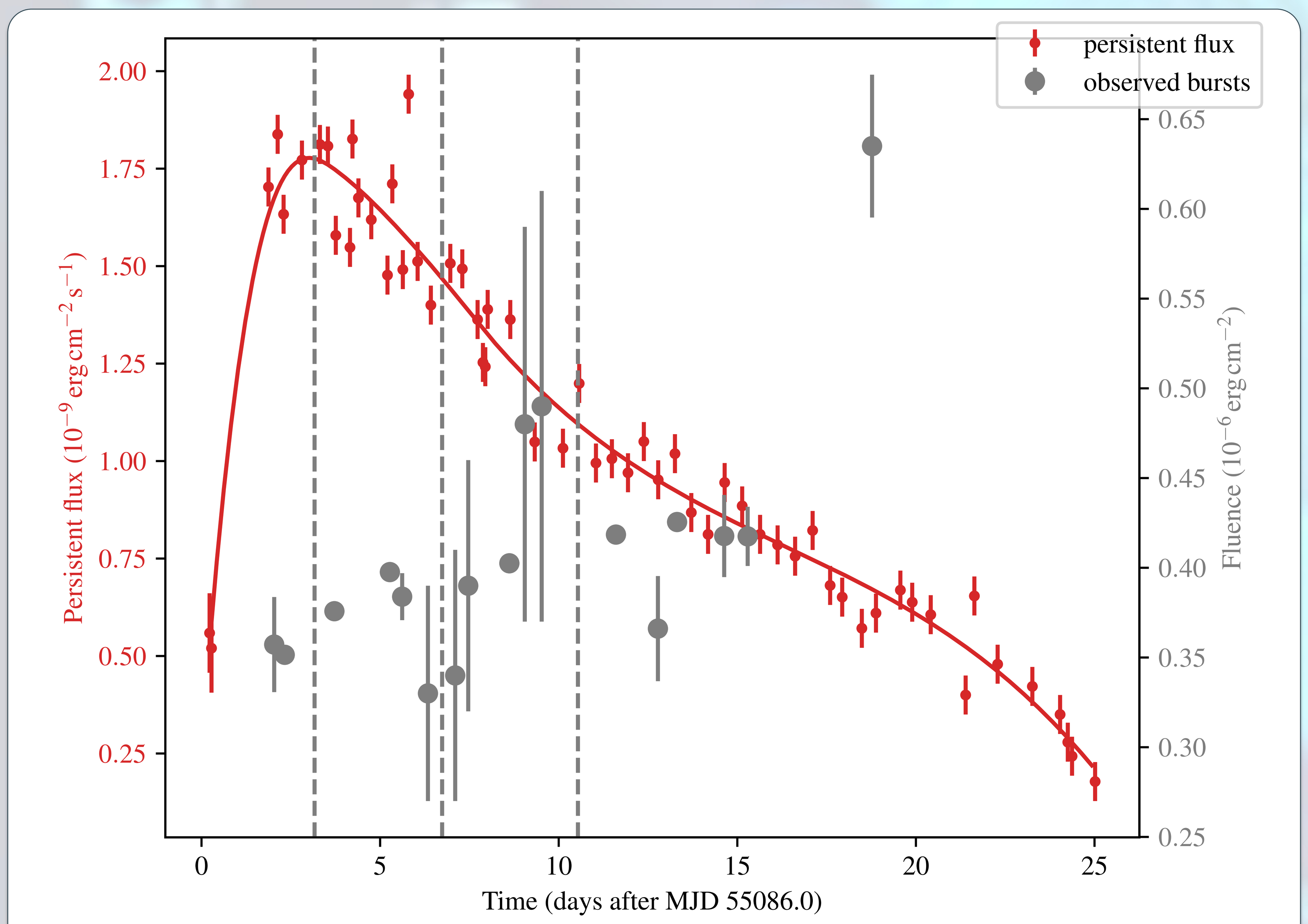

Figure 1: Bolometric persistent flux (red symbols, left-hand y-axis) of IGR J17511–3057 during the 2010 outburst, adopted from [3]. The solid red line is a spline fit to the data. The grey symbols are the corrected fluences (right-hand y-axis) for the burst sample; the times of bursts without a measured fluence are indicated by the gray dashed lines

Results

The burst simulations reproduce the broad features of the bursts from IGR J17511–3057 (Figure 2).

In combination with the previously obtained results from three other sources [4,5] we establish for the first time constraints on the composition and NS properties of a sample of burst sources derived from the burst energetics themselves (Figure 3).

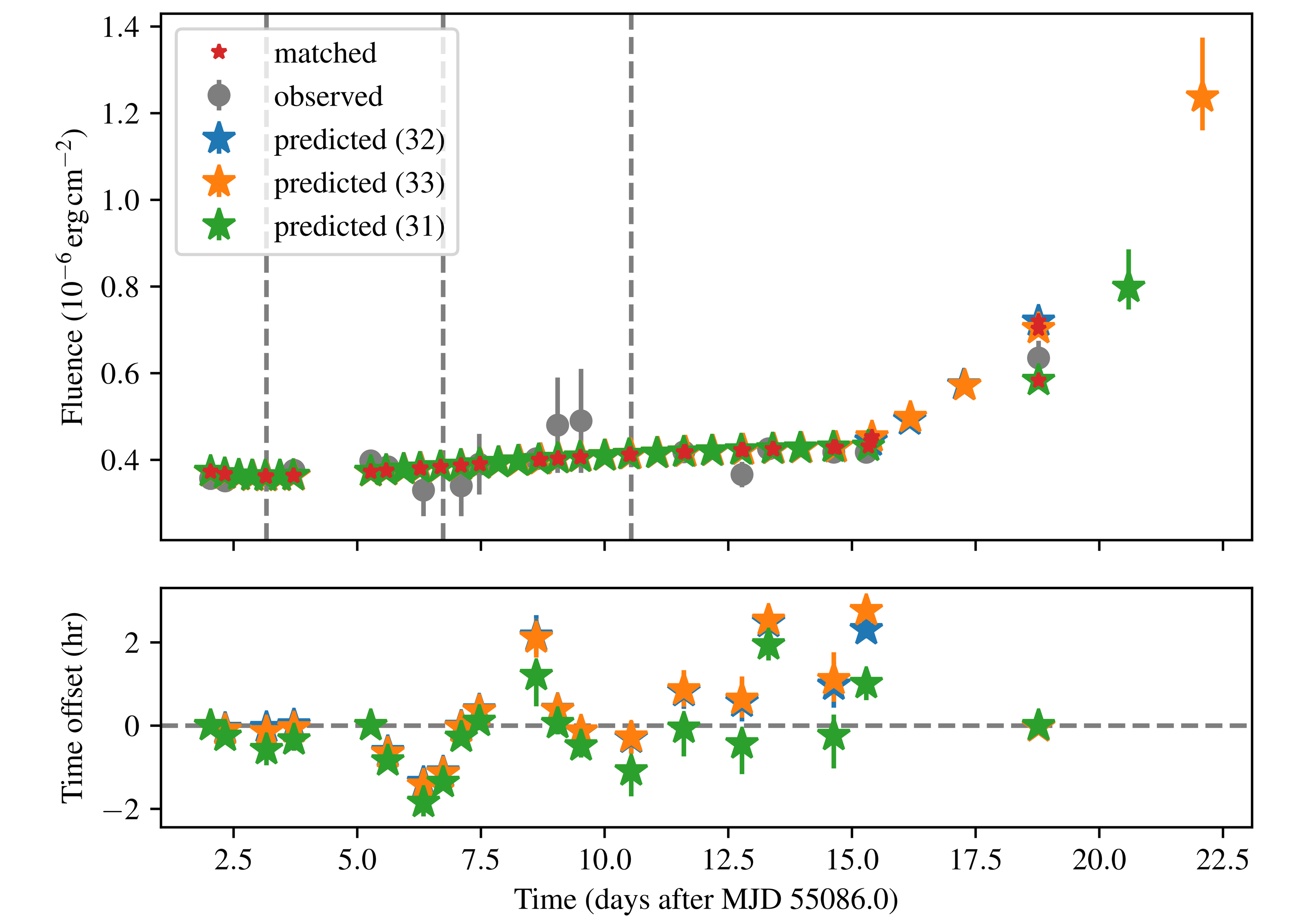

Figure 2: Comparison of a sample of predicted and observed bursts for the piecewise continuous ("punctuated") independent burst train simulation, incorporating also a systematic error on the burst times. The top panel shows the burst fluences overlaid with the separate predicted posterior samples, illustrating the good agreement.
The bottom panel shows the time residuals for the matched bursts; the RMS error is 0.85–1.12 hr. Note the residual systematic variations in the burst times, which may be attributed to a mismatch between the estimated and actual accretion rate.

References

1. BEANSP https://github.com/adellej/beans
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3. Falanga et al. (2011), A&A 529, A68, doi: 10.1051/0004-6361/201016240
4. Galloway et al. (2024), MNRAS 535(1), 647, doi: 10.1093/mnras/stae2422
5. Johnston et al. (2020), MNRAS 494 (3), 4576, doi: 10.1093/mnras/staa1054

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