Reconciling observations and models of thermonuclear bursts: a progress report

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The wide variety of thermonuclear (type-I) bursts from accreting neutron stars present a challenge to modellers. Even for the best-behaved sources, attempts to match observations to numerical models in detail have been limited (e.g. [1,2]), due both to the computational cost and the difficulty for modellers to access fully-analysed observational data.

Here we report on ongoing efforts to address these problems:

- Assembly of a set of "reference bursts" with calibrated data to encourage model comparisons [3]

Source	Bursts	Ref.
GS 1826–24	mixed H/He (case III)	1
SAX J1808.4–3658	pure He (case IV)	2
4U 1820–30	pure He (no H accreted)	4
4U 1636–536	superburst	5

- Assembling a library of model predictions for bursts and ash compositions, and code for detailed comparison with data (see Johnston poster)
- Comparisons of different numerical models, that is beginning to refine our knowledge of burst energetics (see box "Neutrino flux from bursts")
- Application to much wider samples of observed and simulated bursts to fully quantify the systematic uncertainties that arise from astrophysical conditions

Measuring fuel composition

A fundamental measurable for observers is the fuel composition, primarily the H-fraction X_0, inferred via the nuclear burning energy Q_{nuc} and the effect of steady burning prior to ignition. Estimates typically ignore the uncertainty introduced by the unknown neutron star mass and radius, CNO abundance, and system inclination (e.g. [6]). Modelling is under way to quantify these effects, based on simulated data (Fig. 1).

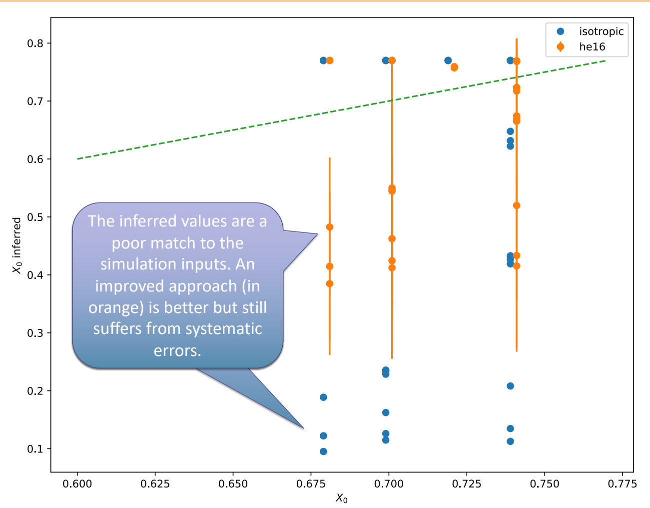

Figure 1: Variations in the inferred H-fraction X_0 inferred from simulated bursts as a function of the astrophysical uncertainties. The blue dots show the values inferred assuming isotropic burst emission and the literature estimate for Q_{nuc}. The orange symbols show the estimates made using the new formula for Q_{nuc} and taking into account the uncertainty in the system inclination (and hence the emission anisotropy).

Neutrino flux from bursts

Our KEPLER simulations have revealed that the neutrino flux from bursts has been overestimated. The burst energy is usually estimated from the average hydrogen fraction of the fuel layer incorporating 35% energy lost in neutrinos from beta-decays. Our simulations show that the neutrino losses are much smaller (Fig. 2), because β-decays are not the sole source of burst energy. We have derived a new relation for the burst energy (Fig. 3; Goodwin et al. 2018, in prep).

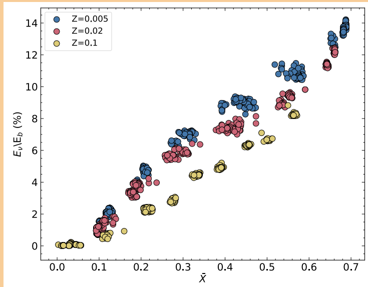

Figure 2: The ratio of neutrino energy to burst energy for a range of initial hydrogen fractions and metallicities (Z). $\bar{X}$ is the average hydrogen mass fraction of the ignition column. Yellow points correspond to Z_{CNO} = 0.1, red to Z_{CNO} = 0.02 and blue to Z_{CNO} = 0.005.

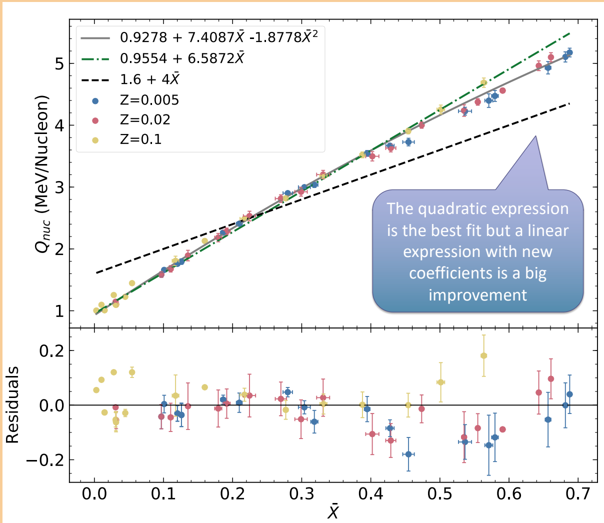

Figure 3: KEPLER Q_{nuc} predictions (circles) for a range of metallicities and initial hydrogen fractions, as a function of the mean H fraction in the column at ignition, $\bar{X}$. Note the poor agreement with the commonly-used relation $Q_{nuc} = 1.6 + 4\bar{X}$. The residuals to the improved quadratic fit are plotted in the lower panel.

An "explosive" future

We anticipate that these efforts will allow us to quantify in detail the typical model uncertainty related to simulations of thermonuclear bursts, and differences between model codes. Establishing burst-model comparisons as a viable method to constrain the rates of individual reactions will offer complementary measurements to nuclear experiment.

If you're a member of JINA-CEE, get involved in the burst project, listed under MA2 on the wiki

References

Click on the link in the QR code to learn more!

[1] A. Heger, A. Cumming, D. K. Galloway & S. E. Woosley 2007, ApJ 671, L141
[2] D. K. Galloway & A. Cumming 2006, ApJ 652, 559
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[4] A. Cumming, ApJ 595, 1077 (2003)
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[6] C.-C. He and L. Keek, ApJL 819, 47 (2016)

http://burst.sci.monash.edu/reference

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