Self-Consistently Exploring X-Ray Burst Reaction Rate Sensitivities

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Forging Connections
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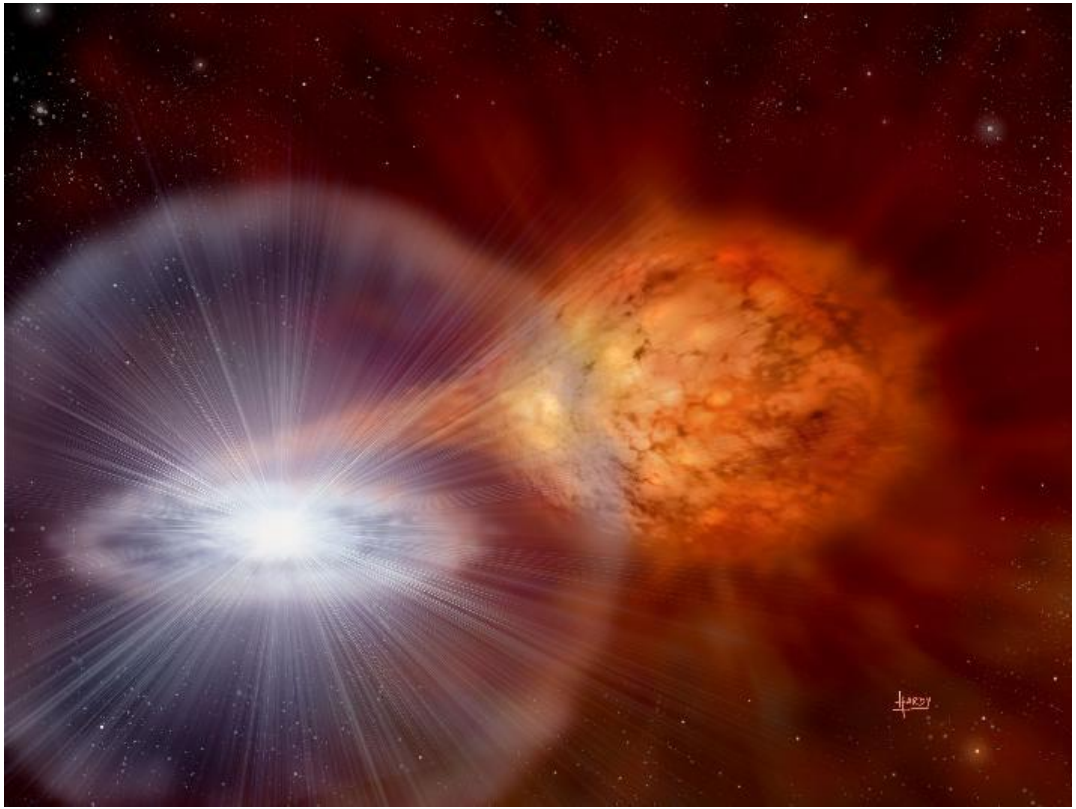
Today’s discussion

1. X-ray bursts as probes of the nuclear equation of state
2. Modeling bursts in spherical symmetry
3. New burst reference database
4. Preliminary results of rate variations with new reference fit
5. Conclusions

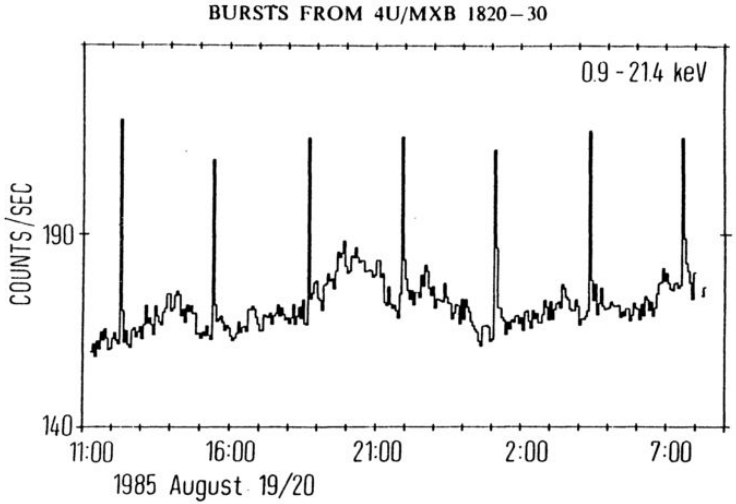
X-Ray Bursts

The ubiquitous X-ray burst picture

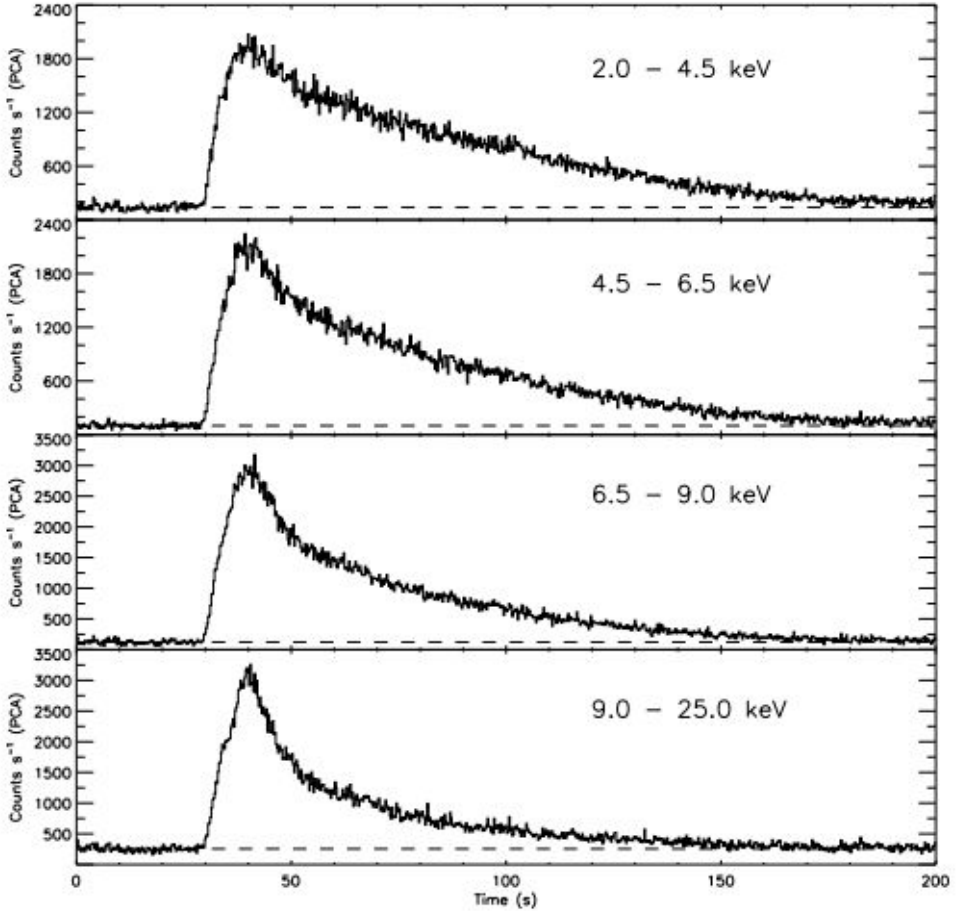


http://www.astro.uva.nl/research/cosmics/thermonuclear-x-ray-bursts/

What it really looks like



Lewin, van Paradijs, & Taam, 1993



Strohmayer & Bildsten, 2006

Bursts as probes of dense matter EoS

- Cooling curves probe crust properties
- Photospheric radius expansion can probe neutron star mass-radius relation:

$$L_{Edd} = (4\pi cGM/\kappa)\left(1 - 2GM/c^2R\right)^{-1/2} = 4\pi R^2 \sigma T_{eff}^4$$

- Need correct models to properly extract M-R

Reactions driving the burst: the rp-process

Strohmayer & Bildsten, 2006

- Triple-alpha, He-chain
- Hot CNO cycles, triple-alpha / He-burning at early phases
- Breakout reactions lead to rp-process, alpha-p process
- Many reactions far from stability, many uncertainties
  - See Cyburt, et al, ApJ, 2016

Modeling X-Ray Bursts

Spherical hydrodynamic models with Kepler

- Kepler code employed to carry out multi-zone models
  - See e.g. Woosley et al., ApJS, 2004
- Models lagrangian grid with reactive fluid equations
- Realistic microphysics, large adaptive reaction network
- Capture details such as radiation and convection

Detailed Observational Reference Set

Galloway, Goodwin, & Keek, PASA, 2017

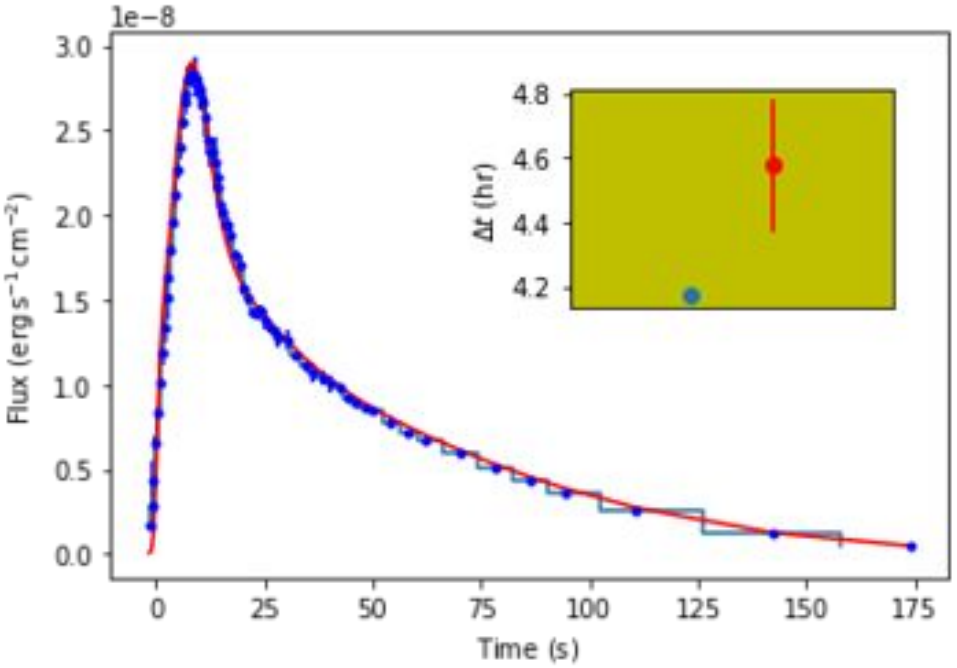
New, rich X-ray burst reference dataset

Table 1 Target thermonuclear burst source properties

Source	Dist. (kpc)	Accreted fuel X_0	Accreted fuel $Z_{\rm CNO}$	$1+z$	g ($10^{14}\,{\rm cm\,s^{-2}}$)	R (km)	Ref.
GS 1826−24	6.1	0.7	0.02	1.23	*2.34*	12.1	[1,2]
SAX J1808.4−3658	3.4 ± 0.1	$0.48^{+0.12}_{-0.08}$	$0.017^{+0.007}_{-0.005}$	*1.26*	*1.86*	*11.2*	[2]
4U 1820−303	7.6 ± 0.4	$\lesssim 0.1$	*0.02*	1.409	2.96	11.1 ± 1.8	[3,4,5]
4U 1636−536	5.6 ± 0.4	*0.7*	*0.02*	*1.26*	*1.86*	*11.2*	

- Specifically for validating and comparing numerical models
- Source data broken into epochs, publicly available
- https://burst.sci.monash.edu/reference

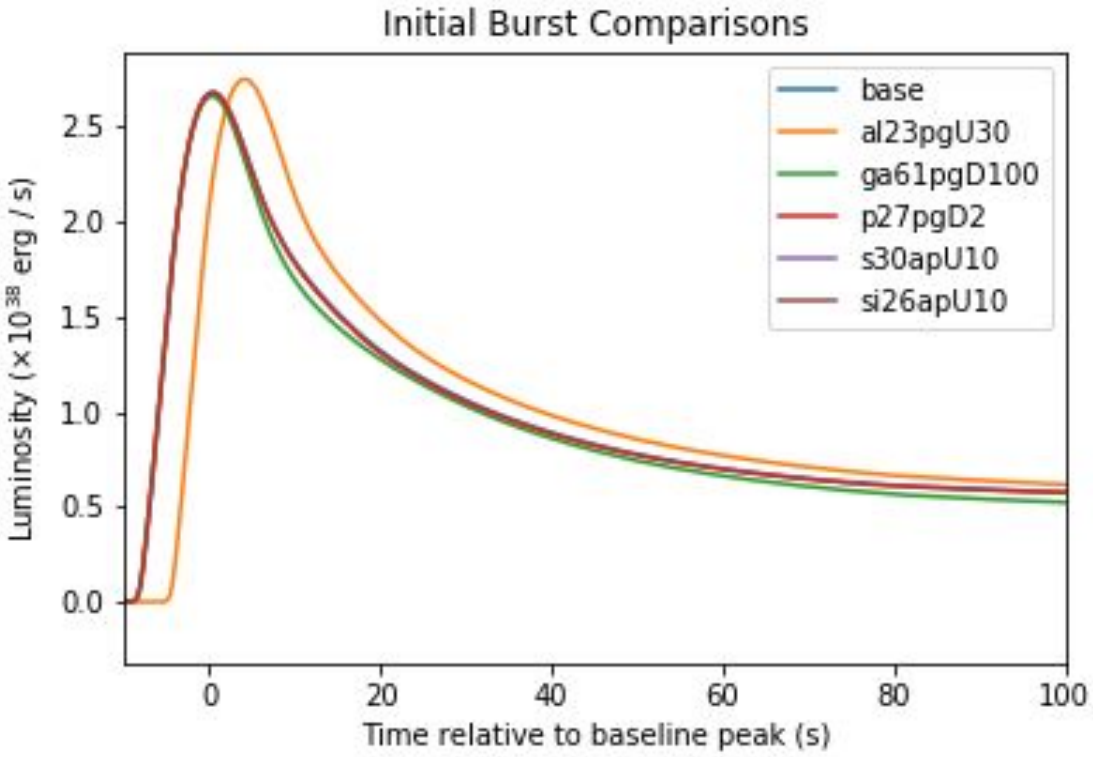
My particular epoch for initial study: GS 1826-24, Epoch 2



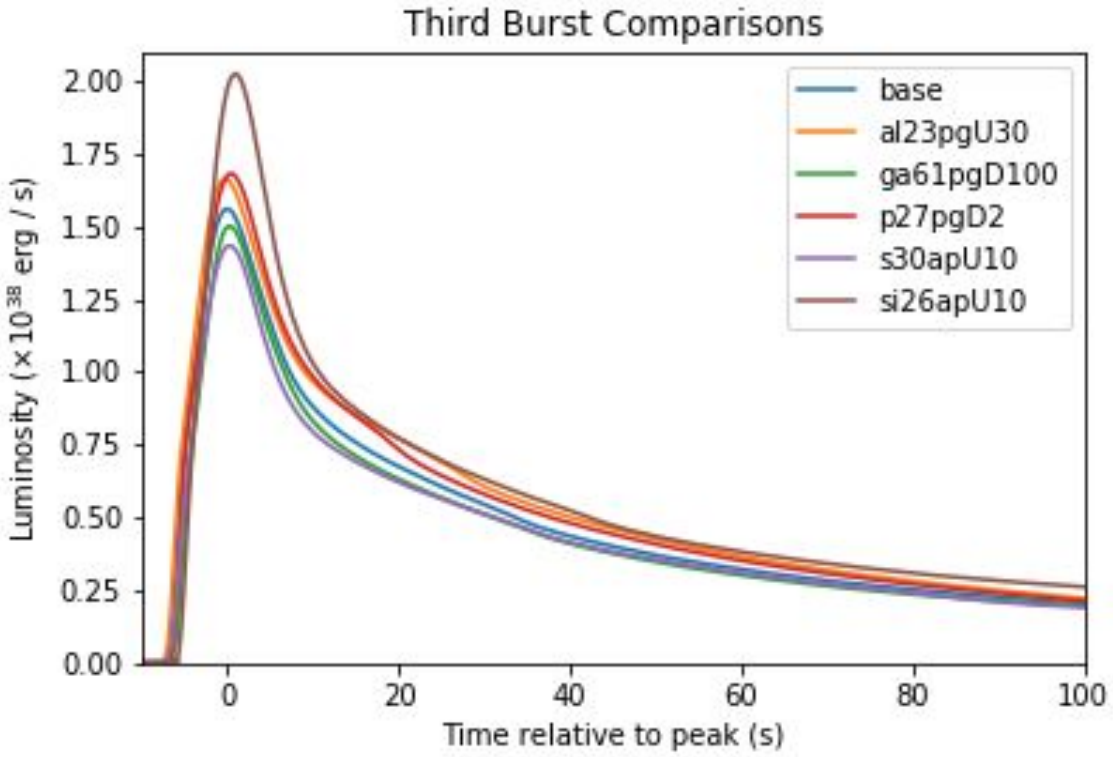
- Brand new best fit provided by Zac Johnston of Monash (private communication, preliminary)
- This baseline will be more directly tied to detailed observation than that of Cyburt et al 2016

Preliminary Results

Light curves for selected varied rates



Light curves for selected varied rates



Conclusions

In Summary

- X-ray bursts are rich laboratories for nuclear astrophysics, and can provide insight into the nuclear EoS and thus into gravitational wave signatures

- With more models becoming available it's crucial to robustly test them against observation

- Pilot study of confronting detailed reference data with Kepler is moving forward. Next:
  - Robust averaging and infrastructure for varying 100s to 1000s of rates and comparing results
  - Develop new baselines and do first detailed multi-zone sensitivity study for the other two reference bursters
  - Work out problems with getting JINA-CEE ReacLib database into models