Status of burst observations

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With contributions from Adelle Goodwin, Zac Johnston, Alexander Heger, the MINBAR collaboration & JINA-CEE working group
A long history of observations

- *BeppoSAX*, wide-field Dutch-Italian mission through ‘90s
- *RXTE* high sensitivity & fast timing, 1995 Dec–2012 Jan
- *INTEGRAL/JEM-X*; wide-field, low sensitivity, 2002 onwards

Data from these last three make up the Multi-INstrument Burst ARchive (MINBAR), under assembly at Monash
http://burst.sci.monash.edu/minbar

- *Swift* & *MAXI*; wide-field, detecting new transients, long bursts etc.
- *NUSTAR*, hard X-ray sensitivity
- *ASTROSAT*, launched Sep 2015, LAXPC large-area detector + imagers
- *NICER*, deployed to the ISS in 2017 June, focus on X-ray pulsations and bursts
A bewildering array of burst types

We observe (and in some cases can explain) a wide range of burst phenomenology

Table 1. Theoretical nuclear burning regimes$^a$.

<table>
<thead>
<tr>
<th>$\dot{m}/\dot{m}_{\text{Edd}}$</th>
<th>Burning regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>~0.1 per cent$^b$</td>
<td>Deep H flash (burns He)</td>
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<tr>
<td>0.4 per cent</td>
<td>Shallow H flashes and deep He flash</td>
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<tr>
<td>8 per cent</td>
<td>He flash (stable H burning)</td>
</tr>
<tr>
<td>11 per cent</td>
<td>Stable H/He burning</td>
</tr>
<tr>
<td>~100 per cent$^c$</td>
<td>Marginally stable burning of H/He</td>
</tr>
<tr>
<td></td>
<td>Stable H/He burning</td>
</tr>
</tbody>
</table>

*Notes. $^a$For solar accretion composition and $Q_b = 0.1$ MeV u$^{-1}$.
$^b$Peng, Brown & Truran (2007), including sedimentation.
$^c$Heger et al. (2007a). See also Keek et al. (2009), Zamfir et al. (2014), Keek et al. (2014).
Status of burst observations

- **We don’t need any more burst observations** *
- We have built up large collections of observational data covering many, many different types of bursts (see arXiv:1712.06227)
- MINBAR sample, with >7000 events from >100,000 observations of 85 bursting sources, and uniform analyses; see http://burst.sci.monash.edu/minbar & shared data provided this week
- These data are sufficient in many cases to answer comprehensive questions about global behavior as well as source-to-source variations (cf. with Galloway et al. ApJL 857, L24; arXiv:1804.03380)
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* We can use new measurements of NS spin; see e.g. Bilous et al. arXiv.org:1805.10065, and Friday’s presentation
* We can learn from new observations of known sources in unusual states, rare events e.g. Jaisawal & Alizai presentations
* We could actually use new epochs of regular (or predictable) bursts from any sources
What we really need
(To fully enable “probes” of nuclear physics)

- We need to **constrain the astrophysical parameters** which determine the burst properties – fuel composition, surface gravity, system inclination (see talks by Goodwin, Johnston)
- Such constraints will hopefully allow us to, in turn, replicate burst behavior with numerical modes (see e.g. Meisel et al., arXiv:1805.05552)
- Which can then be used as tools to constrain nuclear reaction rates and masses
Constraining system parameters method 1

- We can infer the fuel hydrogen fraction \( X_0 \) (and the inclination) from measurements of recurrence time \( \Delta t \), \( \alpha \) (\( = F_p \Delta t / E_b \)) in regular bursts

  - Can estimate \( Q_{\text{nuc}} \) from \( \alpha \), \( \Delta t \), and hence \( \langle X \rangle \) at ignition (cf. with Goodwin talk) up to a factor of \( z \) (redshift) & anisotropy parameters
  - Rate of H-burning then gives an estimate of \( X_0 \) (up to a factor of the CNO metallicity)
  - Shown are the results of simulation parameters for old ("isotropic") and new methods
  - Consistency arguments can also allow constraints on the inclination and possibly also redshift (up to assumptions about the disk shape; e.g. He & Keek 2016)

\[
Q_{\text{nuc}} = \frac{c^2 z \xi_b}{\alpha \xi_p}
\]
We can compare in detail observations (including lightcurves) with numerical models to further constrain the system parameters (cf. Johnston et al. 2018, MNRAS 477, 2112 & talk).

Significant challenges with respect to computational cost and systematic errors for models, but these are being addressed.

New software tools and repositories of model runs are making this process easier, as well as carefully selected datasets from MINBAR (Galloway et al. 2017, PASA 34, e109 & http://burst.sci.monash.edu/reference).
Summary and future work

- Large body of in-hand burst data is an under-utilized resource for probing burst physics (but we’re working on it)
- At the same time new missions (NuSTAR, NICER, ASTROSAT) are providing exciting new observations
- Development of analysis tools and modelling capability is proceeding well and is expected to give results within a timescale of a year
- Contributions most welcome! Join the JINA-CEE burst working group, share progress via the wiki & communicate via Slack