Calm after the storm: burst quenching after a superburst

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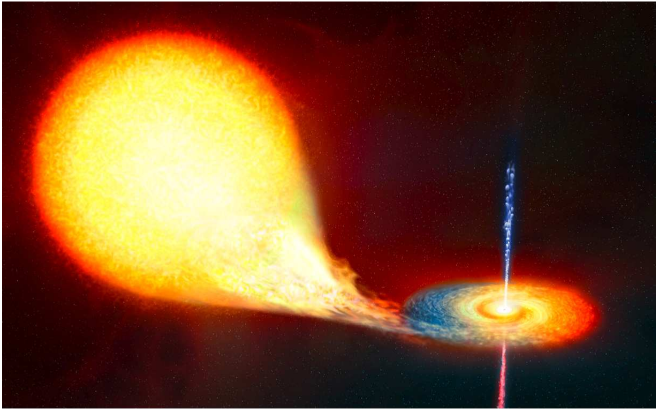
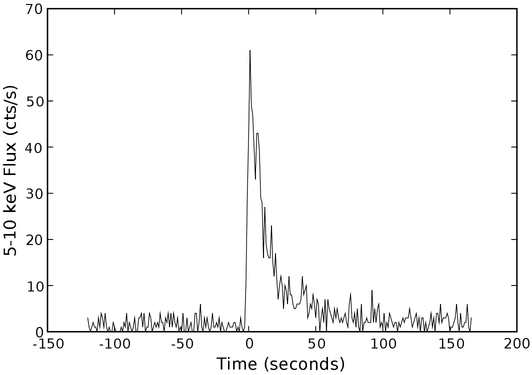
Low-mass X-ray Binary



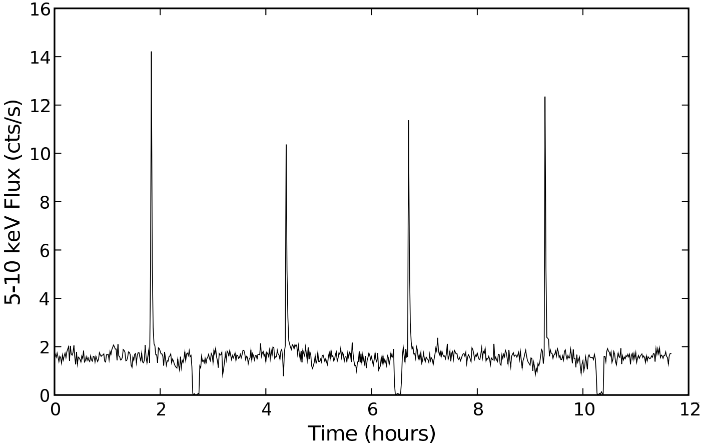
- Compact object: neutron star
- Low mass ($\lesssim M_\odot$) companion
- Accretion rates up to $\sim 10^{-8} \mathrm{M}_\odot \, \mathrm{year}^{-1}$

Type I X-ray burst



- Fast rise (1s), exponential-like decay (10-100s).
- Black-body spectrum
- Thermonuclear burning of a layer of hydrogen/helium.
- Observe neutron star surface.

Nicely regular bursting



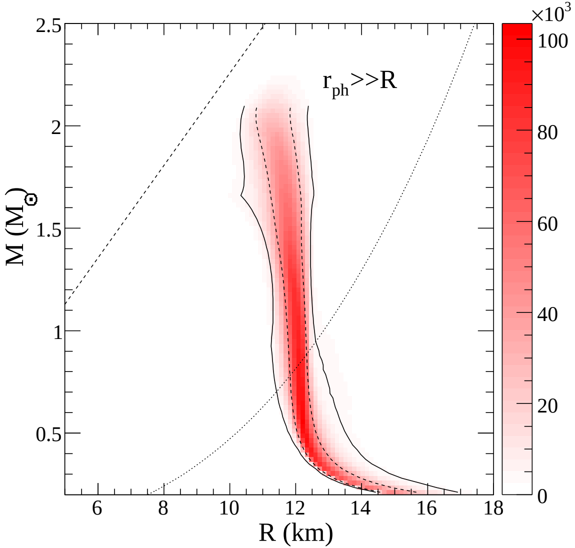
- Recurrence times of hours to days; ∼90 sources
- ∼4000 bursts in Multi-Instrument Burst Archive (MINBAR)

Uses of Type I bursts

Study the core (mass-radius constraints): Equation of State of matter at supranuclear density and finite temperature

- Gravitational redshift of spectral lines
- Radius expansion bursts

Mass-radius constraints



Steiner et al. 2010; more on Monday talks by Miller, Lattimer

Uses of Type I bursts

Study the envelope: thermonuclear reactions of (*heavy*) isotopes

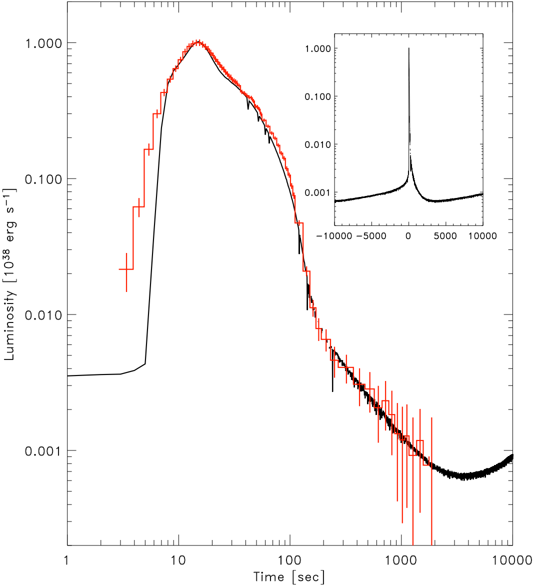
In a layer of 10^{21} g of hydrogen and helium:

- hydrogen to helium: hot CNO cycle (stable)
- helium to carbon: triple-alpha (stable or unstable)

Further reactions:

- alpha capture: αp-process (up to A$\sim$36)
- proton capture: rp-process (up to A$\sim$100)

Success of 1d models



In 't Zand et al. 2009

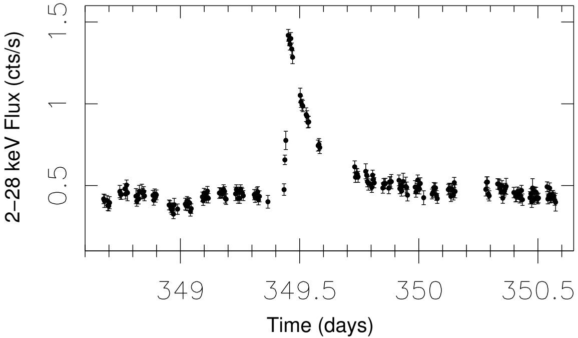
1d models: problems

Mass accretion rate dependence

- Reaction rates depend strongly on temperature
- Burning is stable/unstable depending on temperature
- Mass accretion rate sets heating rate from burning and crust
- Models predict stable burning at 10x higher accretion rate than observed

Tomorrow: multi-d models (Zingale)

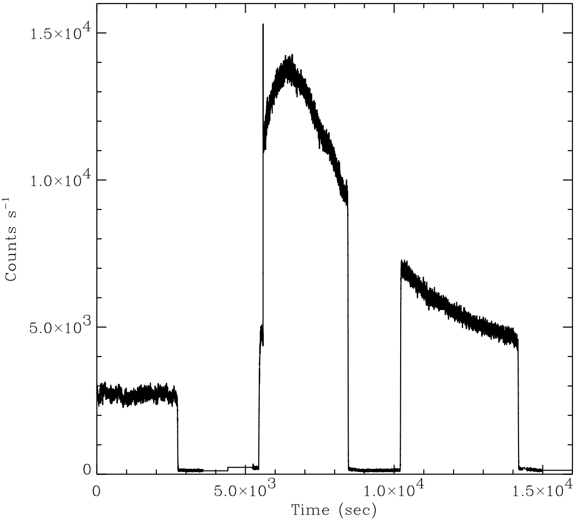
Superbursts



Kuulkers et al. 2002

- 1000x longer decay time (hours), 1000x more energetic
- Rare: only 19 observed from 11 sources
- Ignite on top of crust

Superburst from H-accretor 4U 1636-53

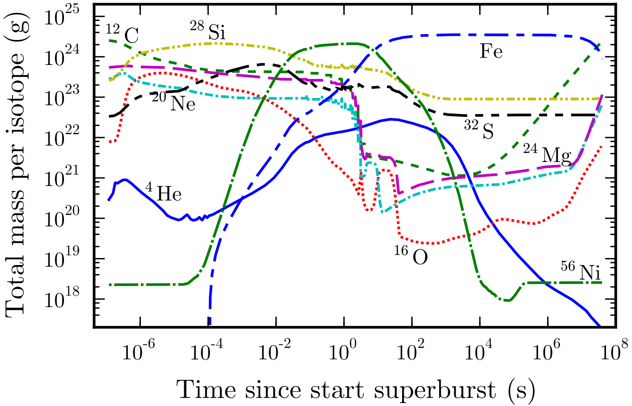


Strohmayer & Markwardt 2002

KEPLER model of superburst

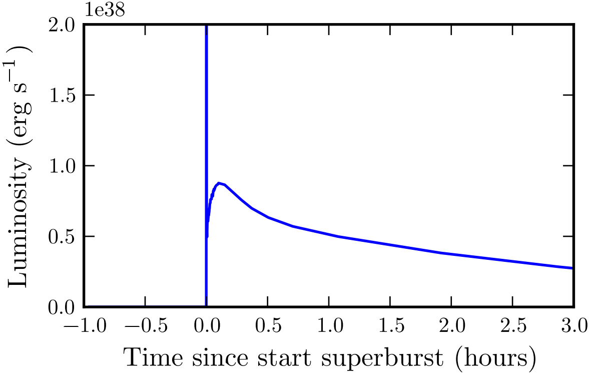
- Accrete 20% ^{12}C and 80% ^{56}Fe
- Neutron star with 1.4 $M_{\odot}$ mass and 10 km radius
- Assume certain accretion rate and crustal heating

Thermonuclear burning



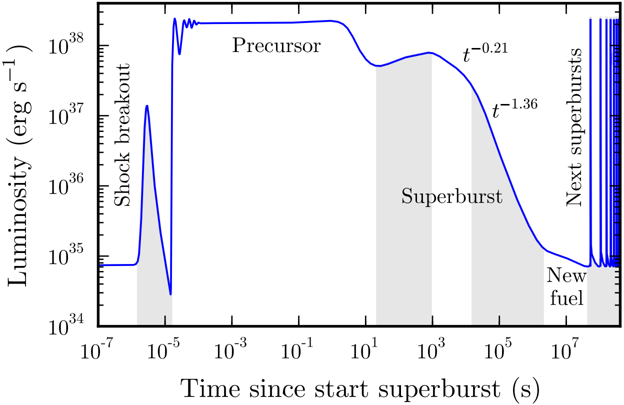
Keek & Heger 2011

Superburst models



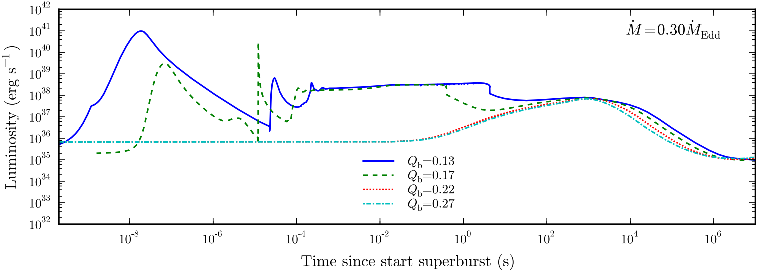
- Reproduce precursor, decay

Superburst model

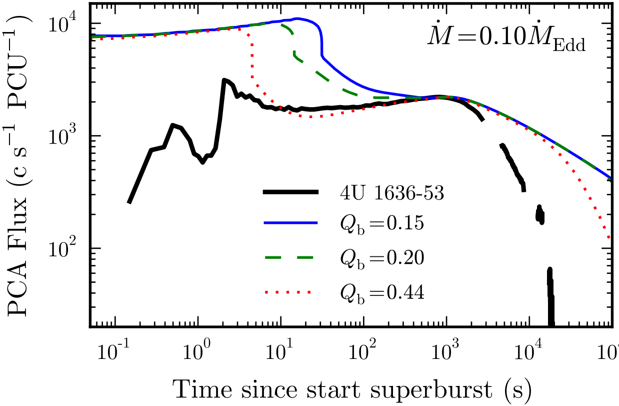


Keek & Heger 2011

Different heating rates



Comparing to 4U 1636-53



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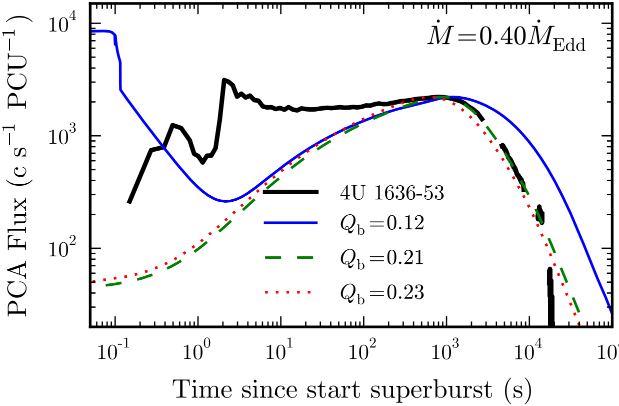
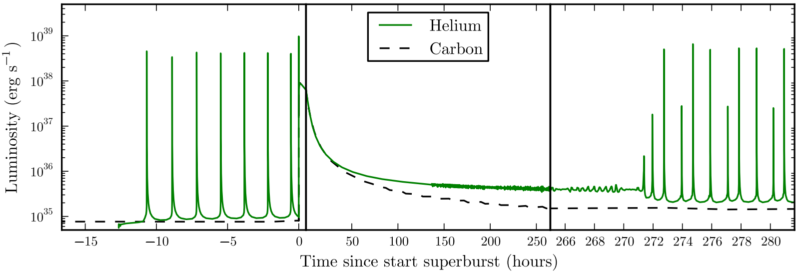
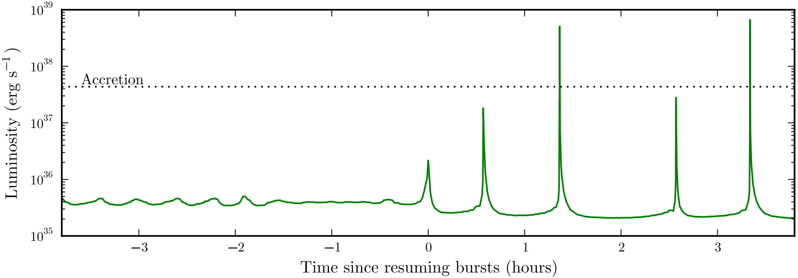


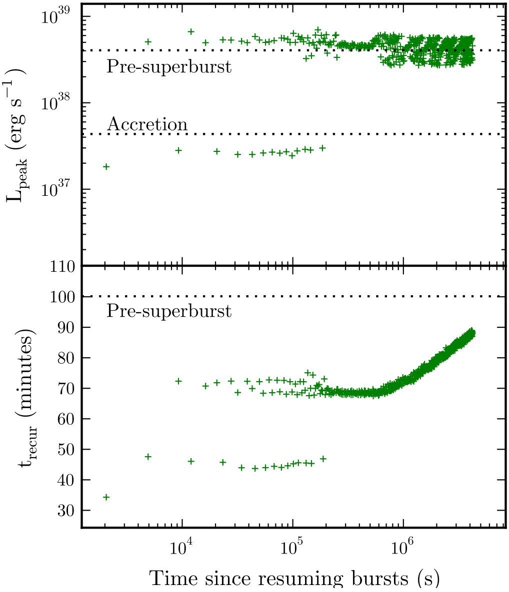
Helium atmosphere



He-bursts reappear



Bursts reappear



Conclusion

Type I X-ray bursts:

- Observe surface of an accreting neutron star
- Get mass *and* radius
- Constraints on heavy isotope reactions

Superbursts:

- Day-long carbon bursts
- Ignite close to neutron star crust

1d models with large nuclear network:

- Reproduce burst light curve, energetics, recurrence times
- Superburst precursor: heating by shock and fallback
- Problem: mass-accretion rate dependence
- Superburst with hydrogen/helium atmosphere: burst quenching