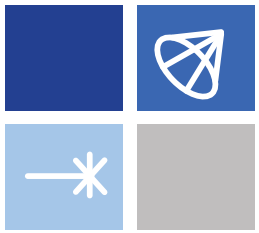
New Burning Physics - Implications for Modes as Explanation of Burst Oscillations

Frank Chambers
University of Amsterdam

BERN 18 - Prato, June 2018



ANTON PANNEKOEK

Thermonuclear X-ray bursts and Burst Oscillations

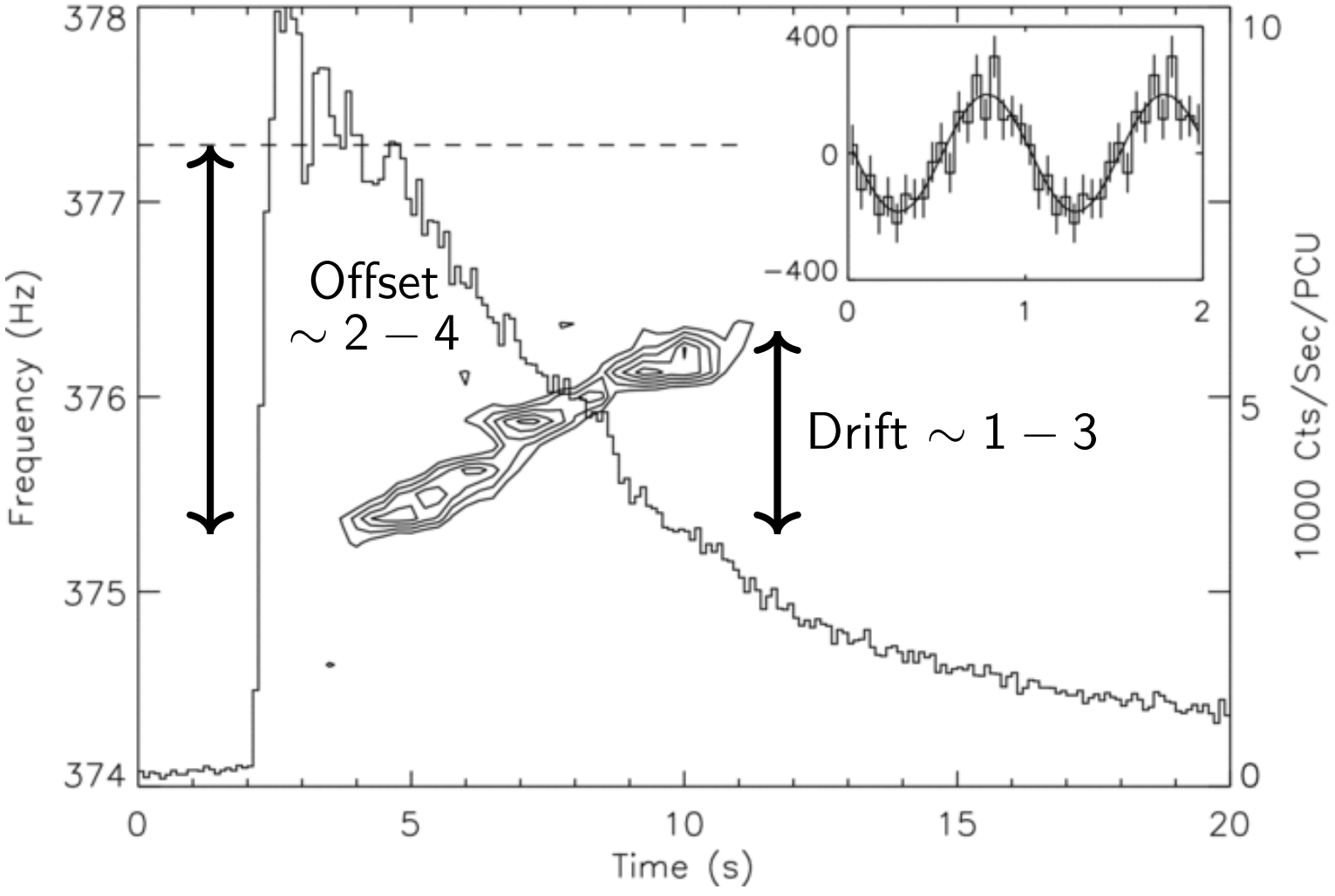


Figure: Watts et. al. 2009, HETE J1900.1

Models for H/He Burst Oscillations

Flame Spread / Cooling Wake

Burning front spreads from ignition site
$\rightarrow$ Spitkovsky et. al. 2002, Cavecchi et. al. 2013, 15, 16, Mahmoodifar & Strohmayer 2016

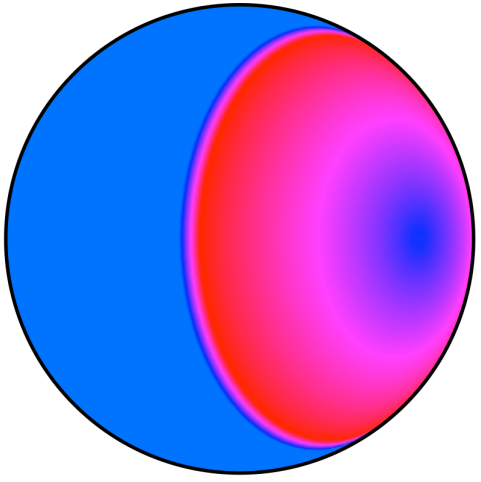


Figure: Watts 2012

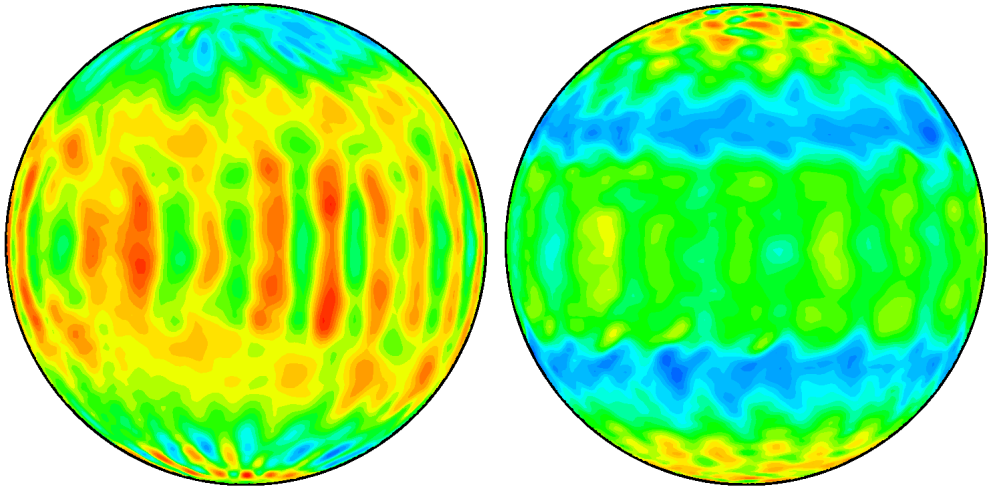


Figure: v_ϕ for $\mathrm{Ra} = 5 \times 10^2, 10^3$

Convective Pattern - Garcia, Chambers, Watts 2018

Convection switches on/off during the burst. **What is the effect of Helium burning?**

Heyl 2004: Ocean Modes

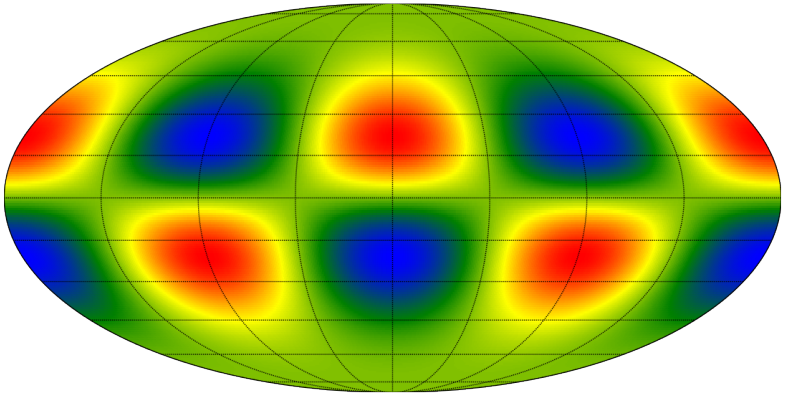


Figure: rotationally modified g-mode, $m = 2$

Bright and dark patches
$\Longrightarrow$ surface asymmetry
Frequency drift
$\Longrightarrow$ atmosphere cooling

$$f_{\text{obs}} = \frac{\omega_{\text{rot}} - m\Omega}{2\pi} \Longrightarrow$$

- $2\pi/\omega \sim 1$ sec
- $m > 0$
- low m, $= 1$

Mode candidate: buoyant r-mode, $m = 1$

Assumptions

Newtonian, Thin shell, Adiabatic,
Traditional Approximation
$\rightarrow$ **Laplace's Tidal Equation**

less variability $\begin{cases} \text{g-modes} \\ \text{Kelvin modes} \end{cases}$

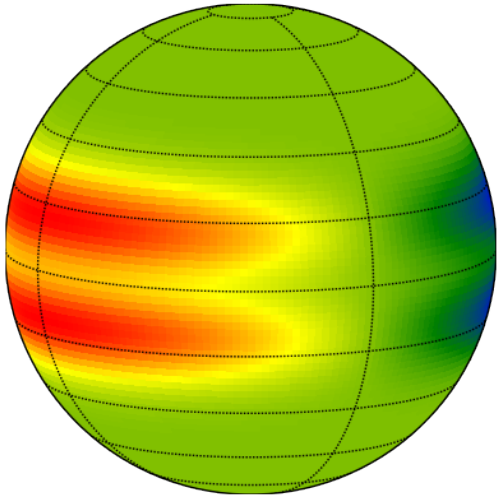


Figure: $l = 2$

Missing Physics

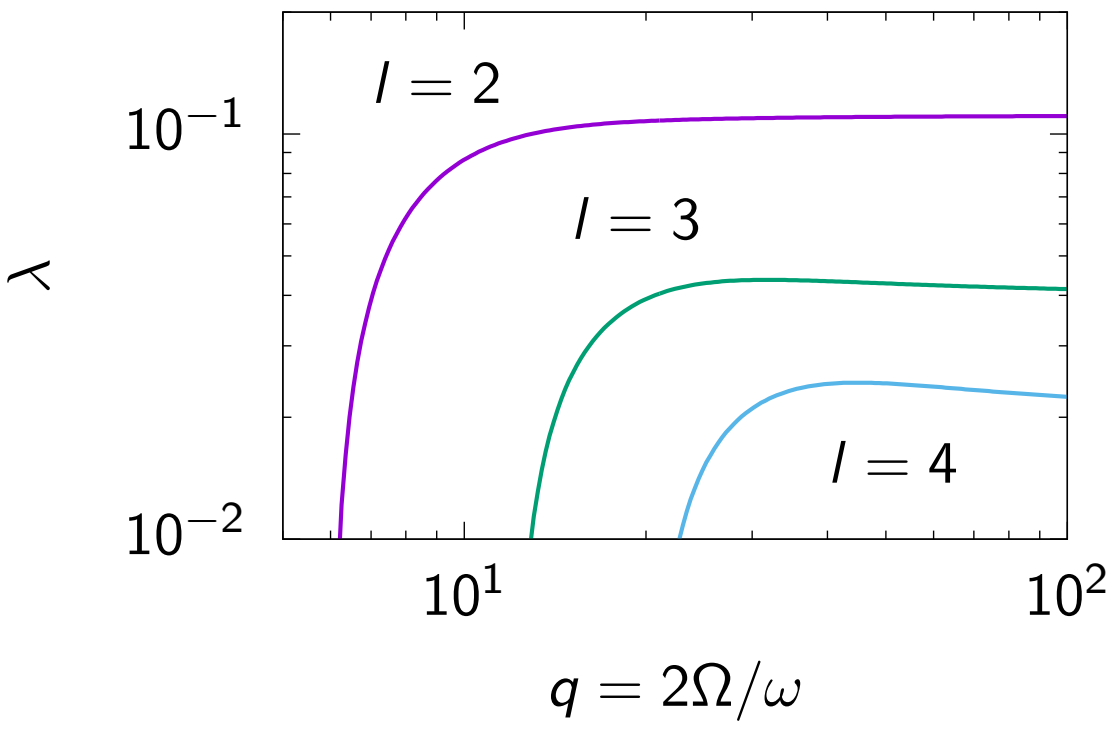
Relativistic Effects $\sim 20\%$ (Maniopoulou & Andersson 2004)
Photosphere interaction, rapid rotation, magnetic field interaction, viscous effects, shear layers?

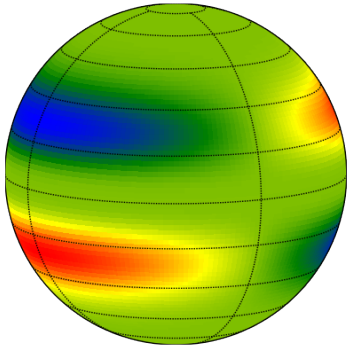
Other r-mode candidates?

Heyl 2004: greater $l \implies$ less visible

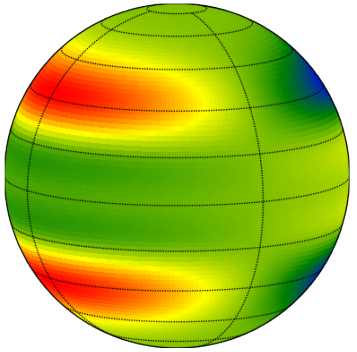
However, smaller λ reduces frequency:

$$\omega \propto k = \frac{\sqrt{\lambda}}{R}$$





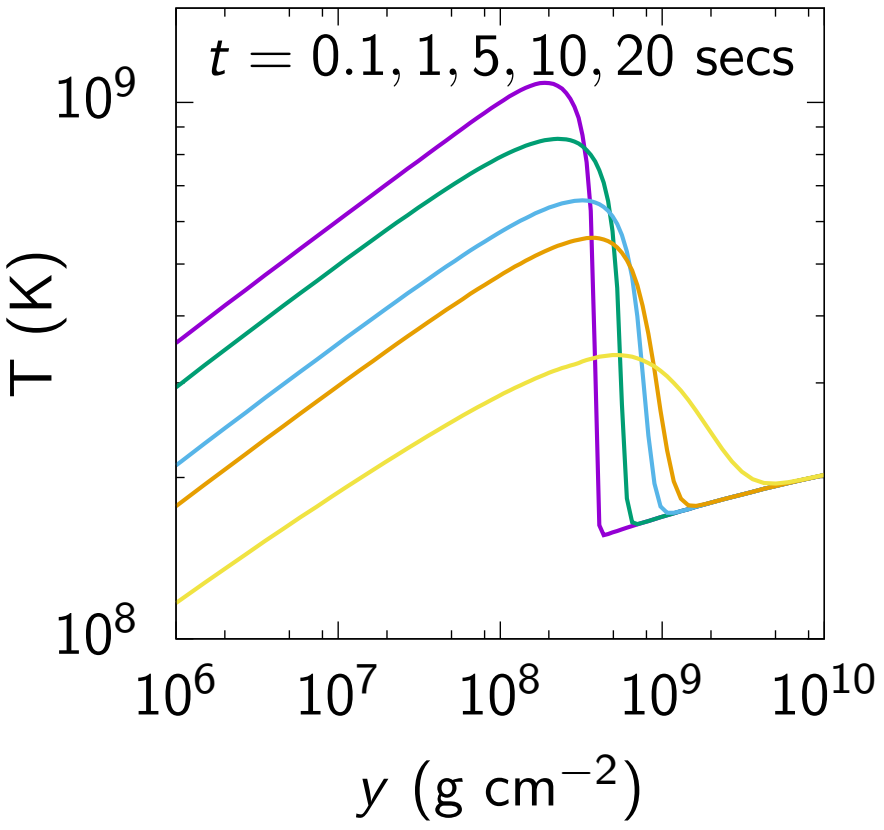
$l = 3$

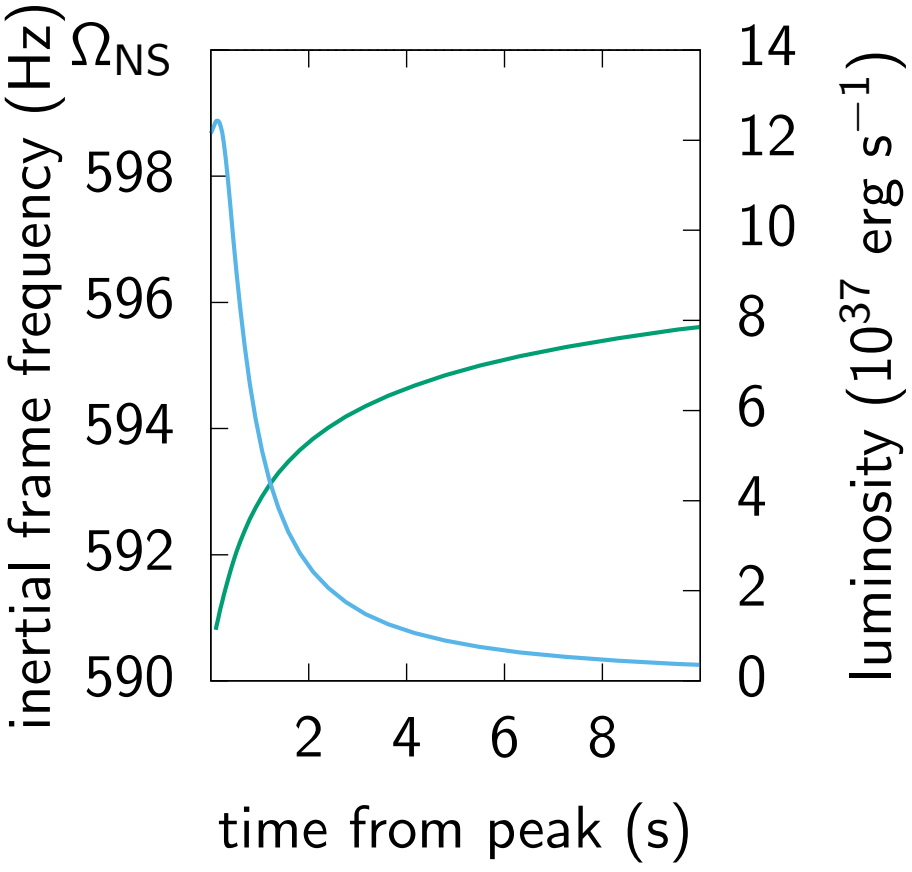


$l = 4$

Piro & Bildsten 2005 - ocean mode

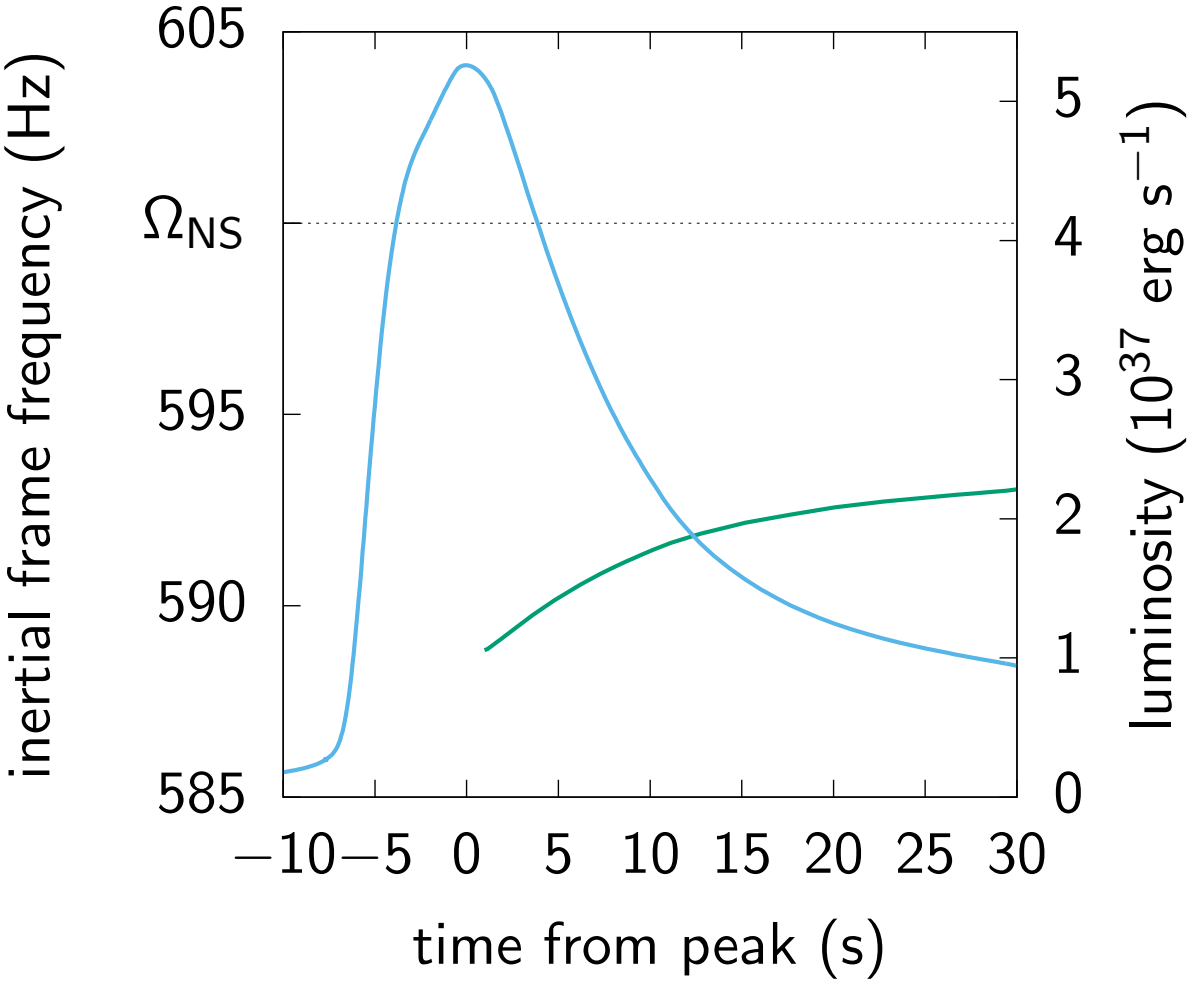
- **only cooling**, no burning during burst
- ocean mode: drift 5 Hz in 10 seconds
- crustal mode: helps → can't work (Berkhout & Levin 2008)





New physics in bursts

Extra sources of heat: Superburst recurrence times, cooling profiles, **H/He short waiting time burst**



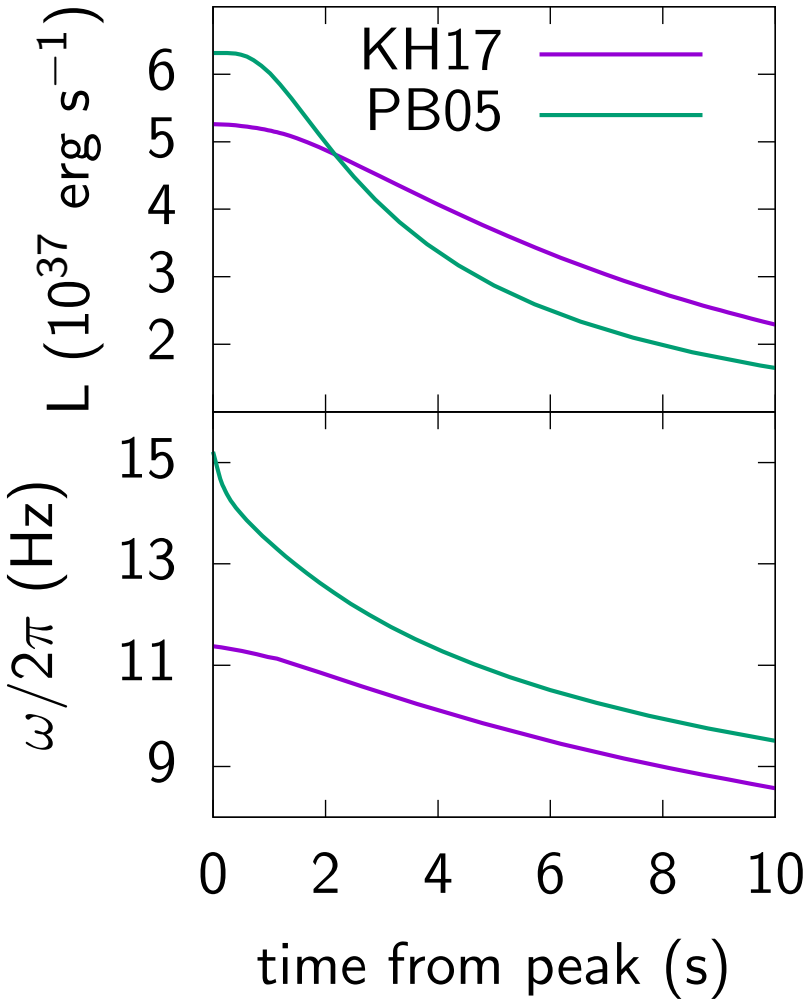
Keek & Heger 2017

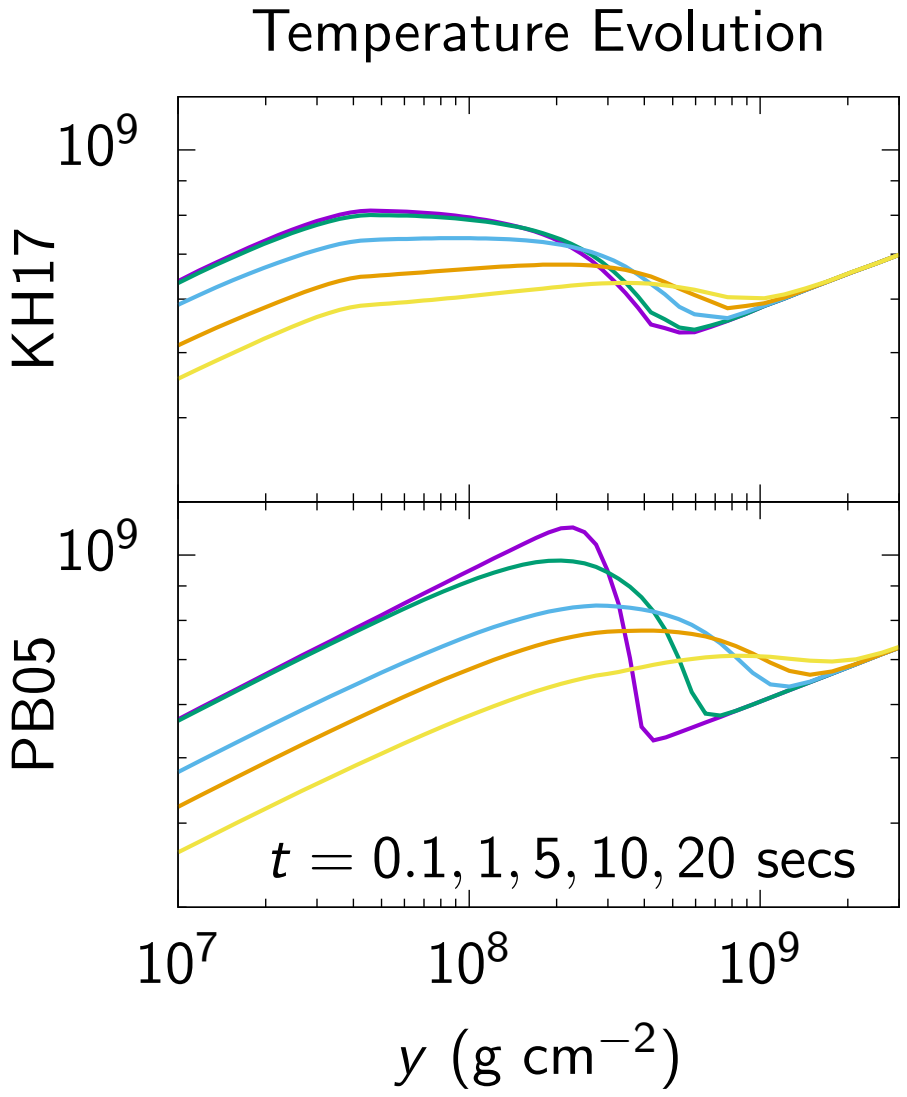
- Burst triplet
- 4U 1636-53
- $Q_b = 3$ MeV nuc^{-1}

Changes:

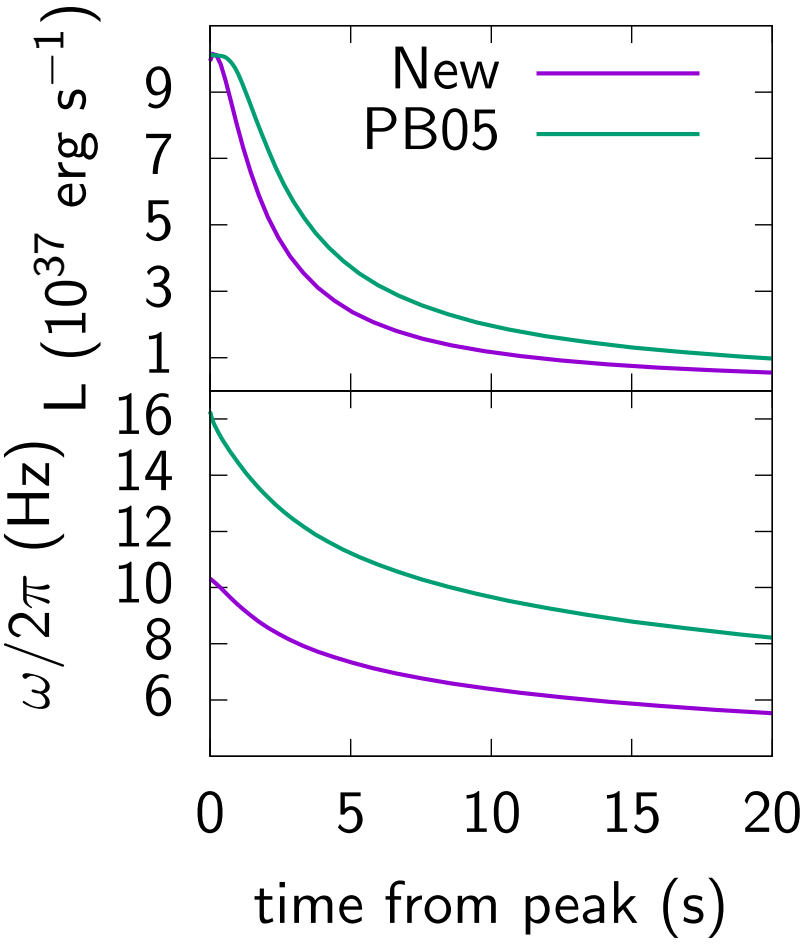
- Burning throughout
- Realistic temperature profile
- Helps with drifts, **not** absolute frequency

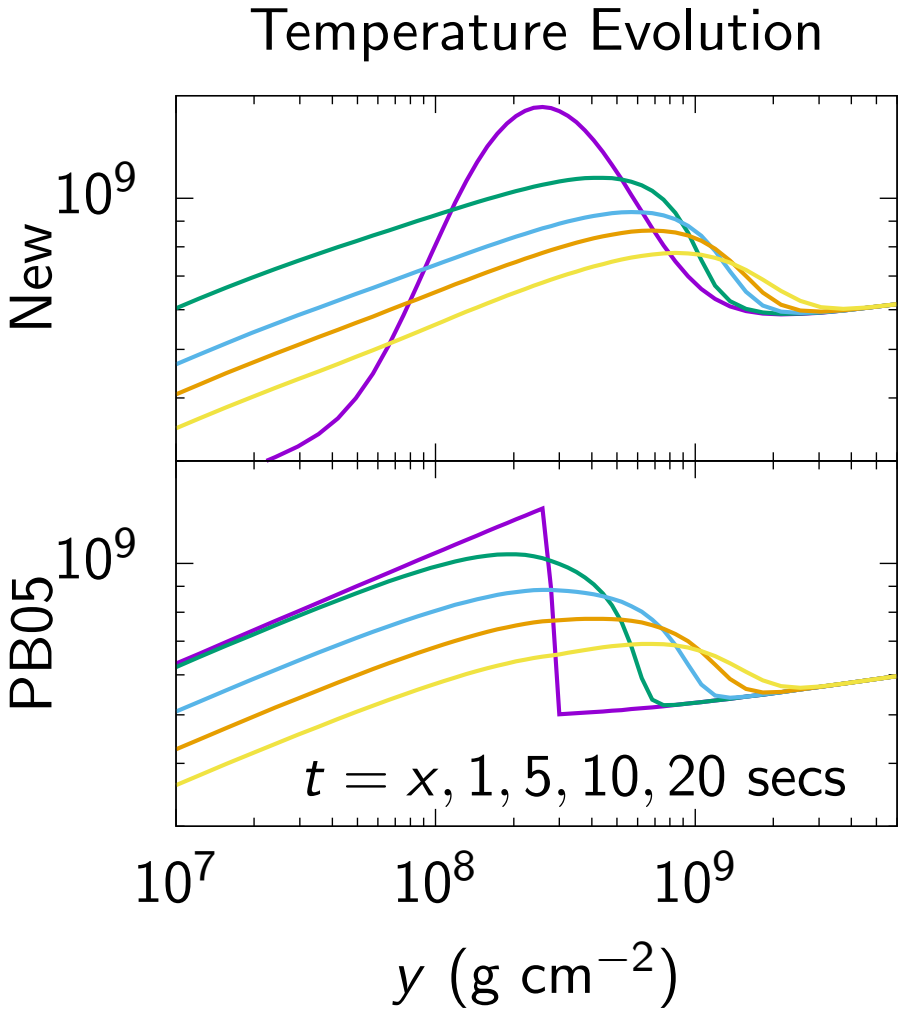
Different temperature profile $\rightarrow$ difference frequencies



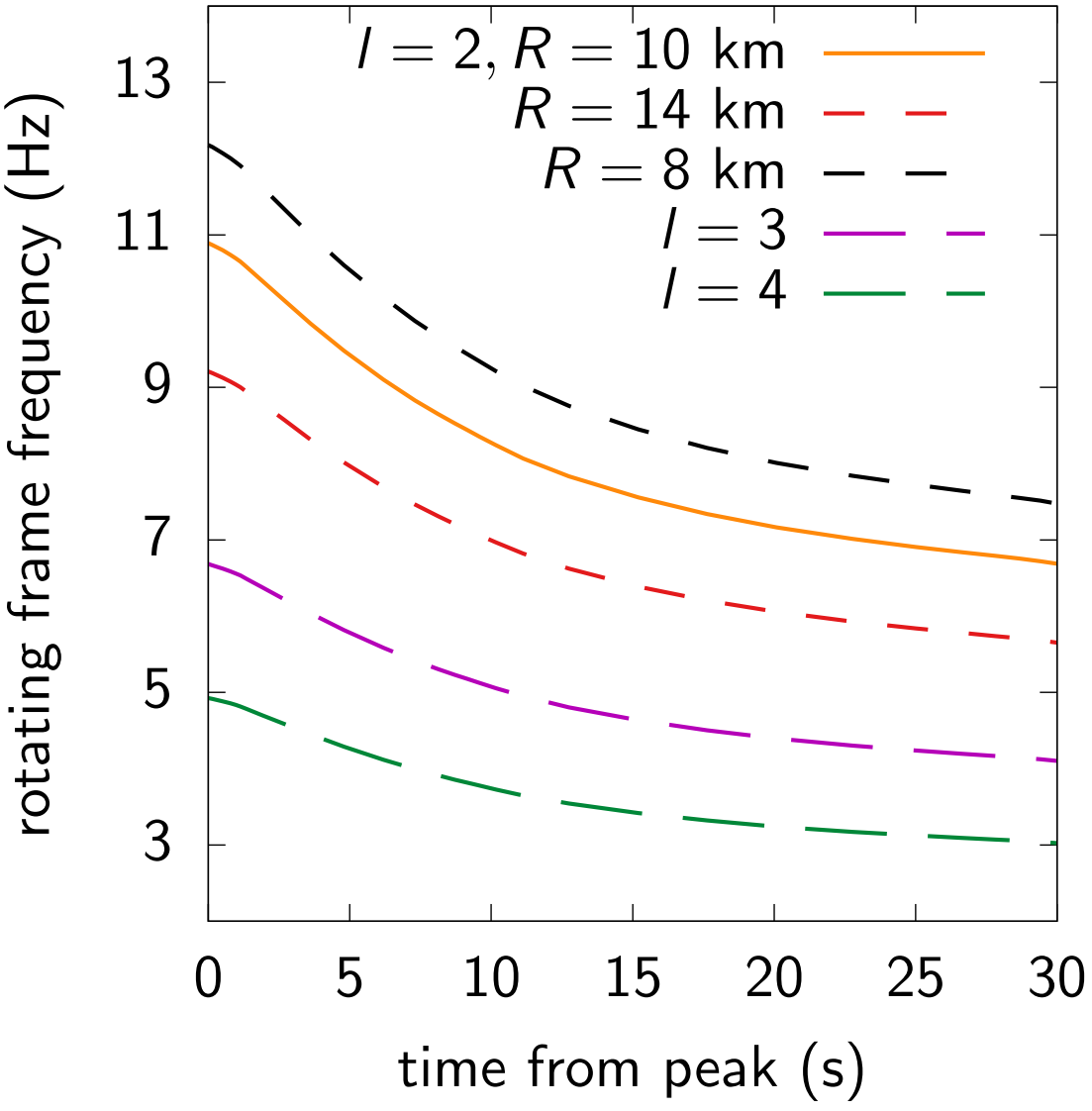


Preliminary! New simple models for background





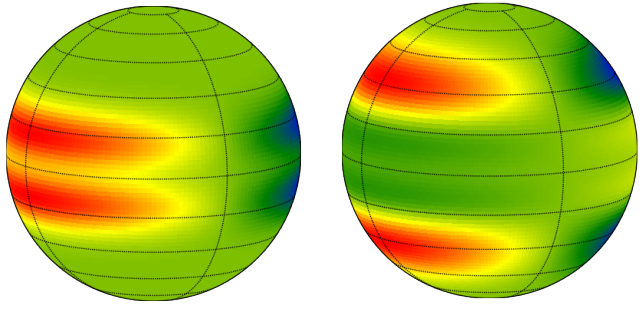
Preliminary! Changing l or R?



Different frequency

$$\omega \propto k = \frac{\sqrt{\lambda}}{R}$$

Visibility?



$l = 2$ $l = 4$

Main points

Take home message

Adding extra heat significantly affects mode frequencies.

BERN-ing questions

Burning physics: How large a temperature perturbations would affect nuclear burning?
Observations: How small a temperature perturbations could be observed?

$\rightarrow$ **Do these overlap?**

Conclusions

Adding physics changes the buoyant r-mode

- Nuclear burning and shallow heating $\Longrightarrow$ drifts are improved
- Altering mode calculation $\Longrightarrow$ offset improved

Missing Physics?

- GR - Changes absolute frequencies, not drifts
- Coupling to photosphere
- Oblation, shear, magnetic field?

Burst Oscillations - Hope for the future

- Revisiting H/He models with Zac Johnston & Adam Jacobs
- New satellite missions (eXTP, Strobe-X) $\rightarrow$ further insight