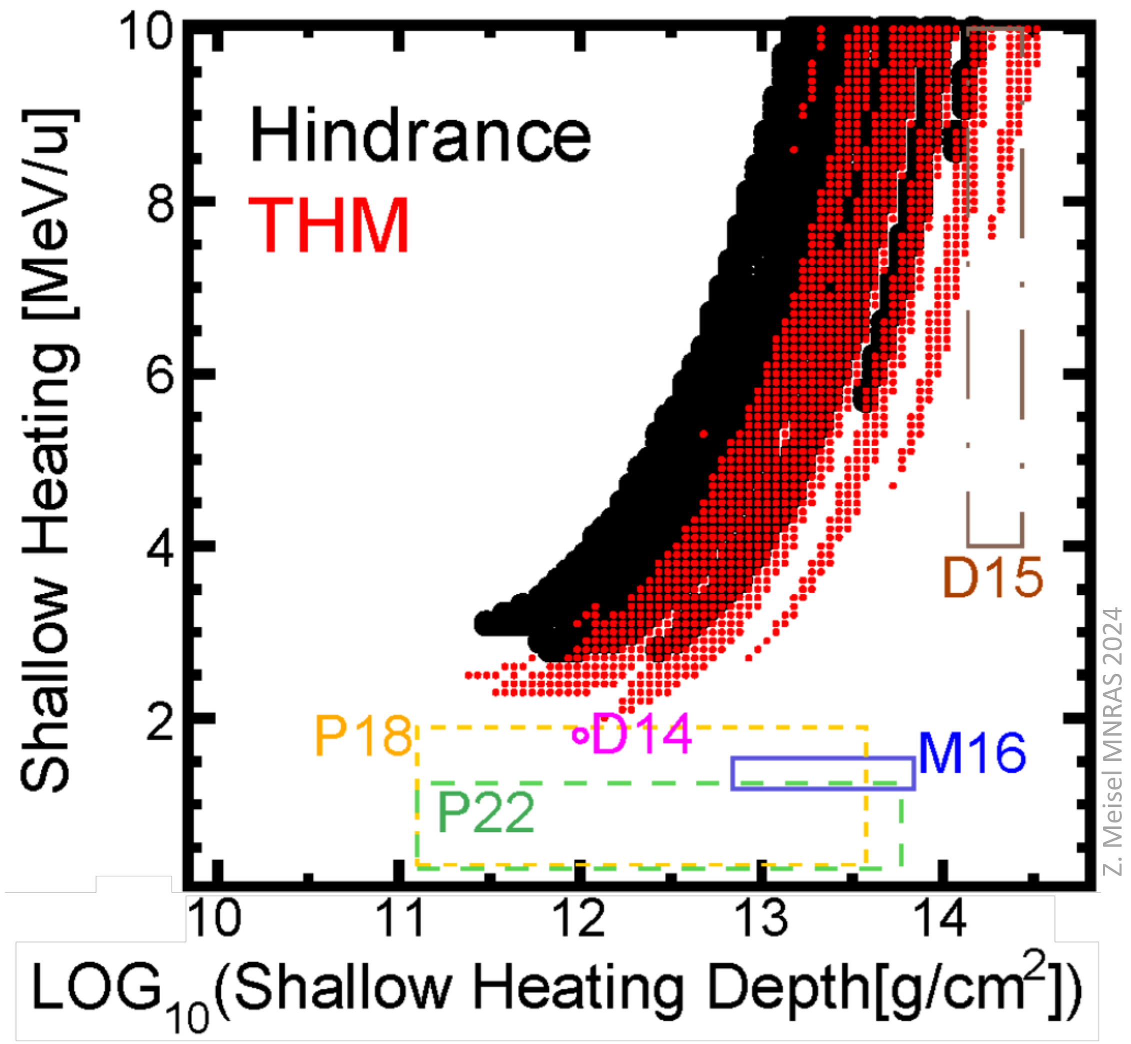
The accreting NS shallow heat source could be constrained using inferred x-ray superburst ignition depths



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IReNA/INT Workshop on Neutron Star Thermal and Magnetic Evolution (December 2024)

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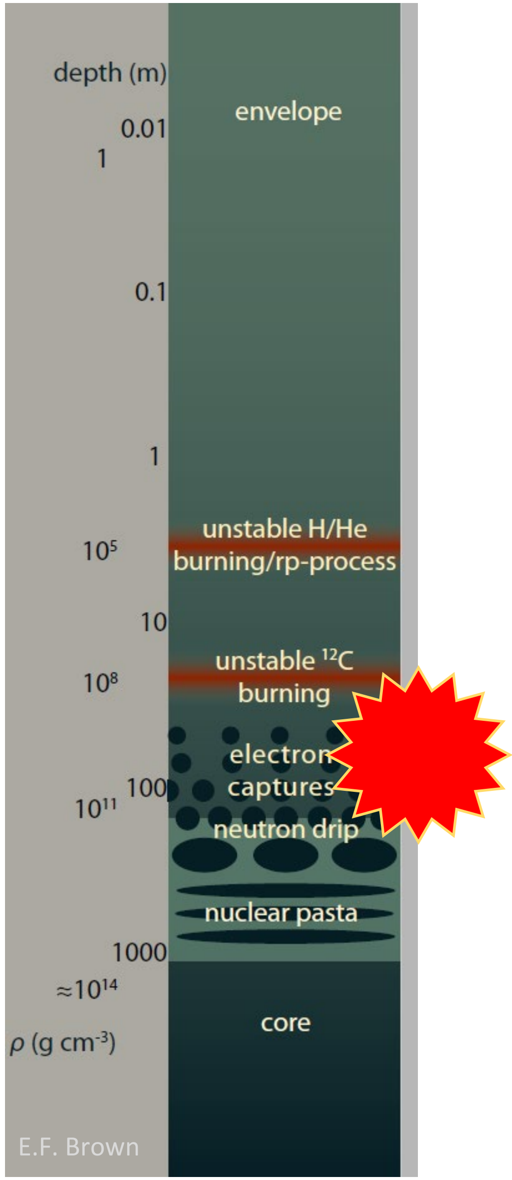
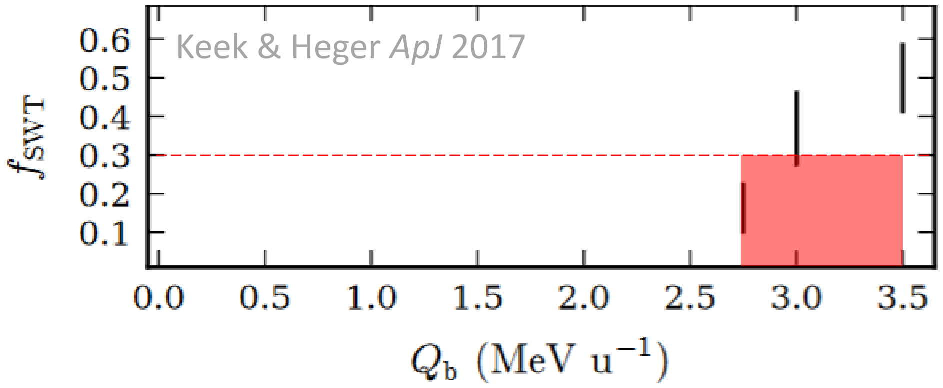
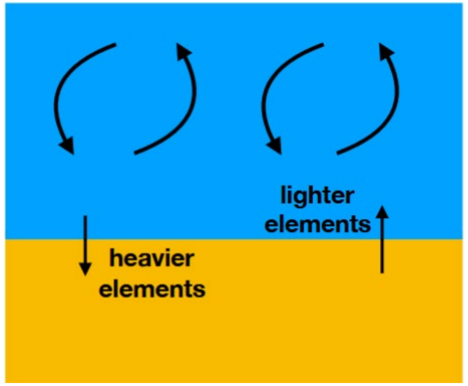
Shallow heating seems necessary, but the mechanism is unclear



Short-waiting-time XRBs

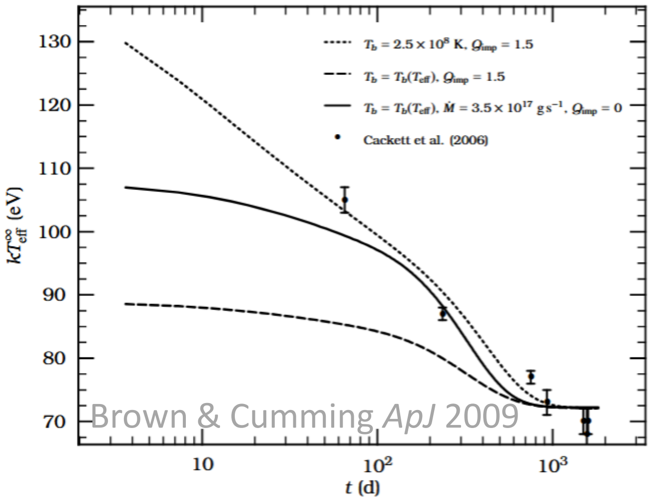


Compositionally-driven convection

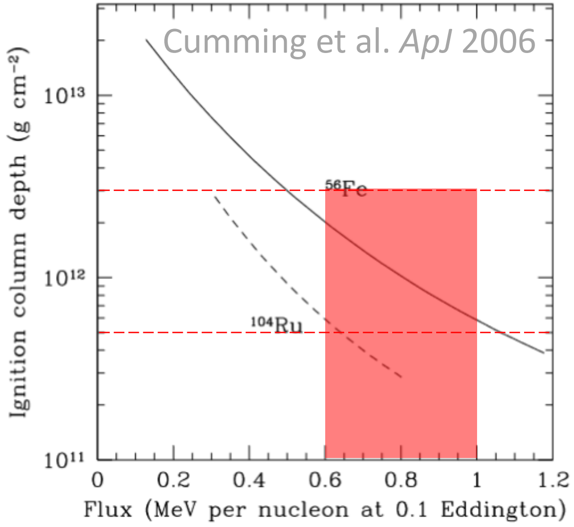


Medin & Cumming *ApJ* 2011 & 2015

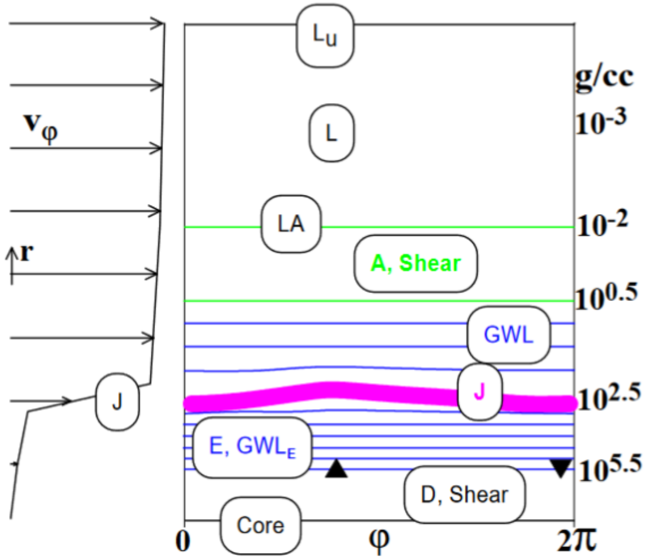
Crust cooling light curves



Superburst ignition depths



Accretion shear + gravity waves

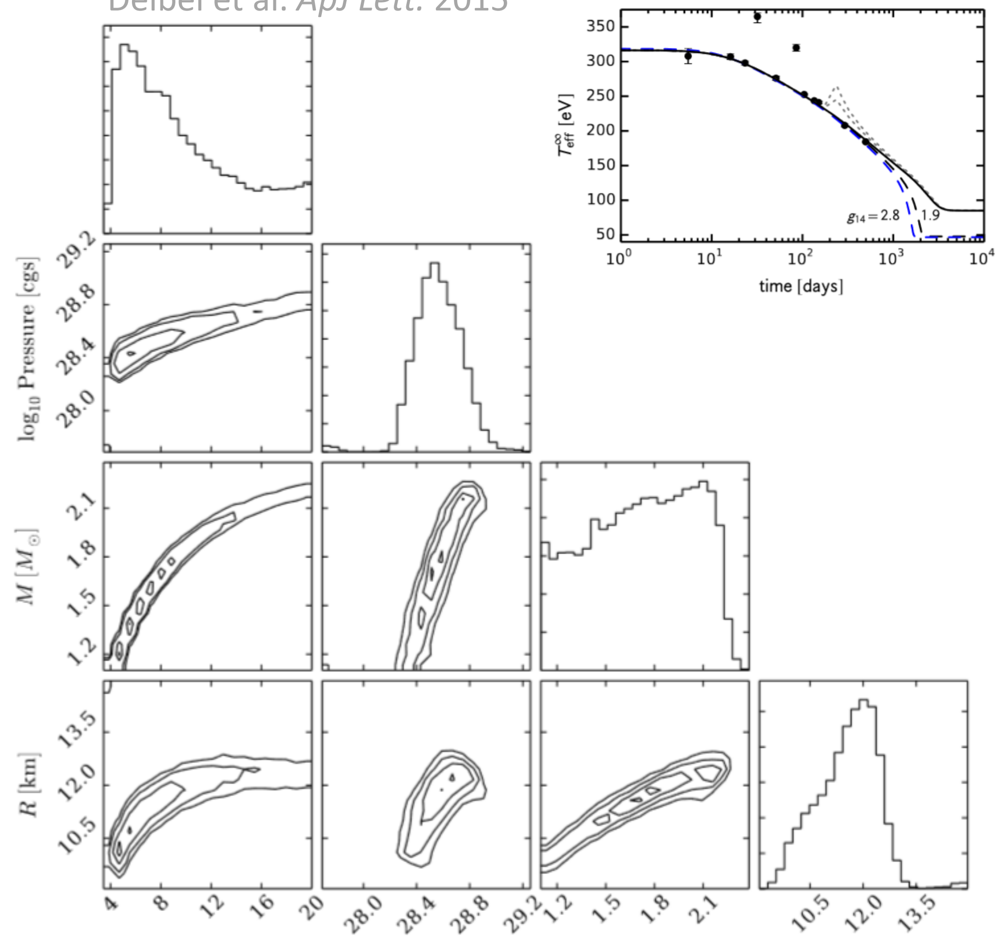


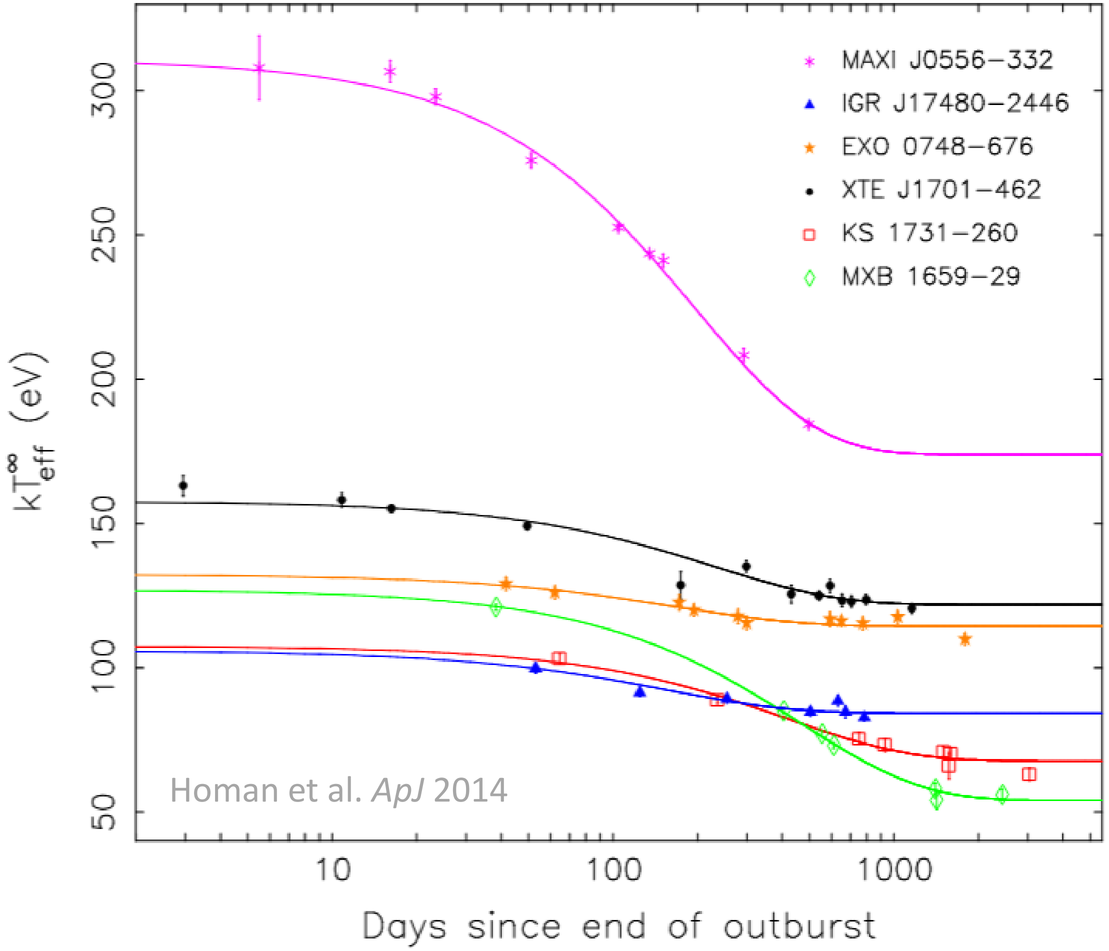
Inogamov & Sunyaev *Ast. Lett.* 2010

AFIT

Crust cooling provides the most stringent shallow heating constraints, but there are a lot of free parameters and only a handful of sources

Deibel et al. *ApJ Lett.* 2015

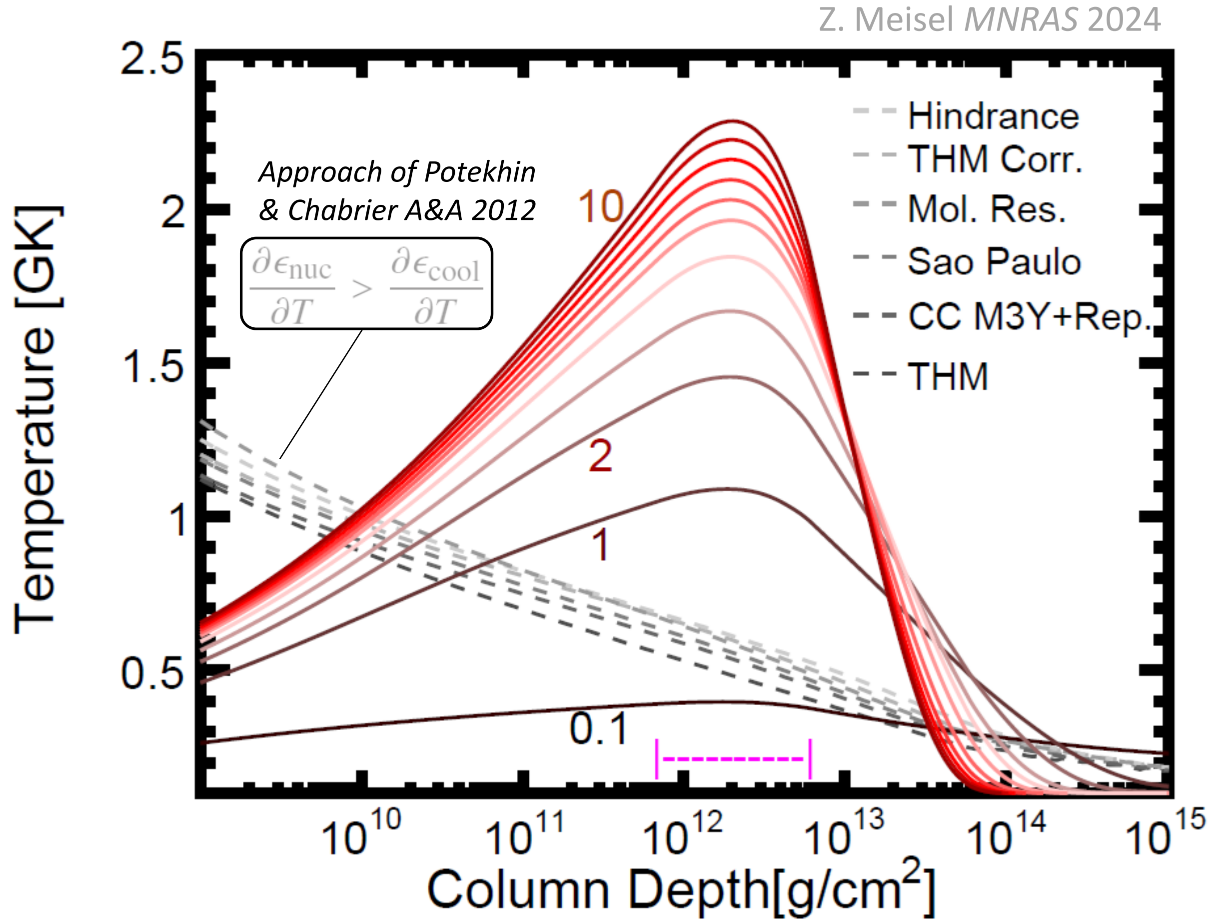


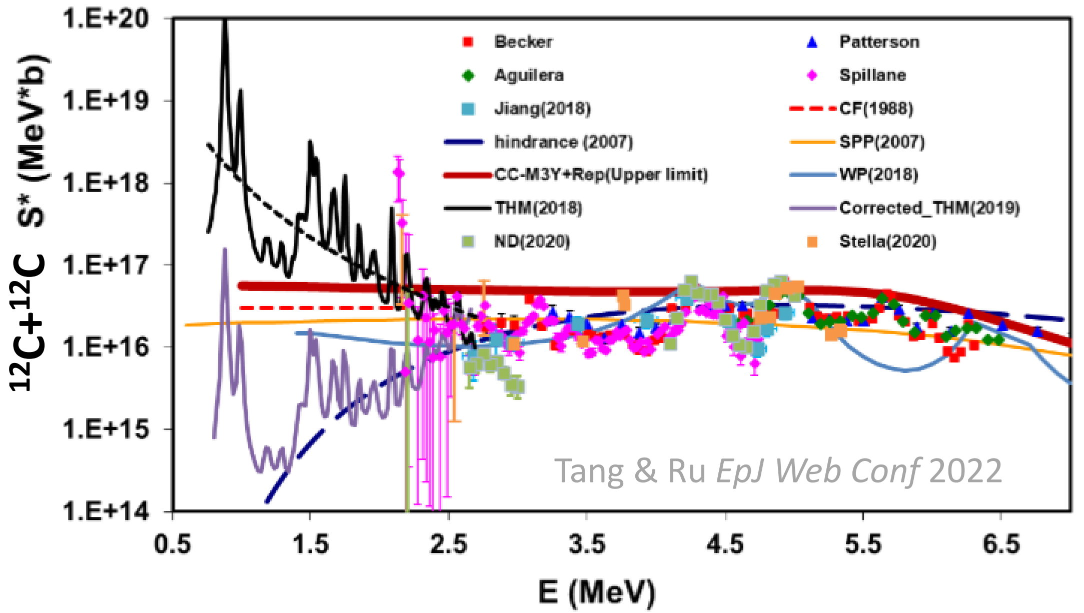


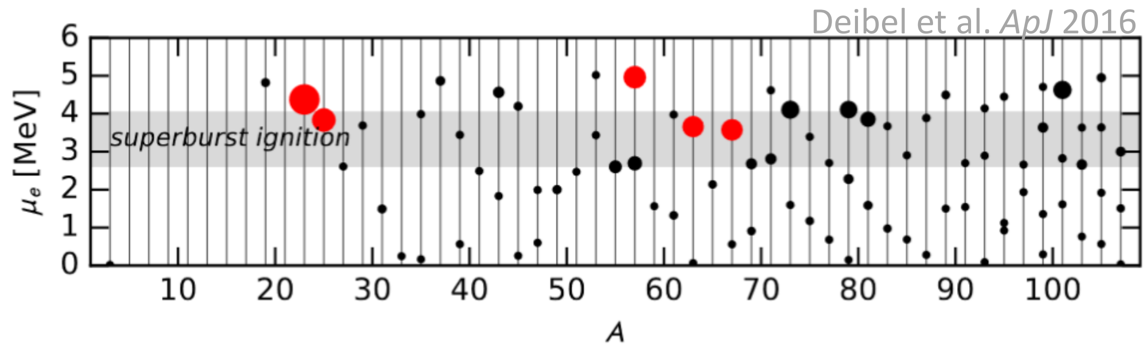
Homan et al. *ApJ* 2014

Superbursting systems could provide complementary constraints.

The depth at which carbon is ignited is very sensitive to the thermal structure of the crust & thus to shallow heating







There are of course astrophysics uncertainties. *Are the nuclear physics uncertainties important?*

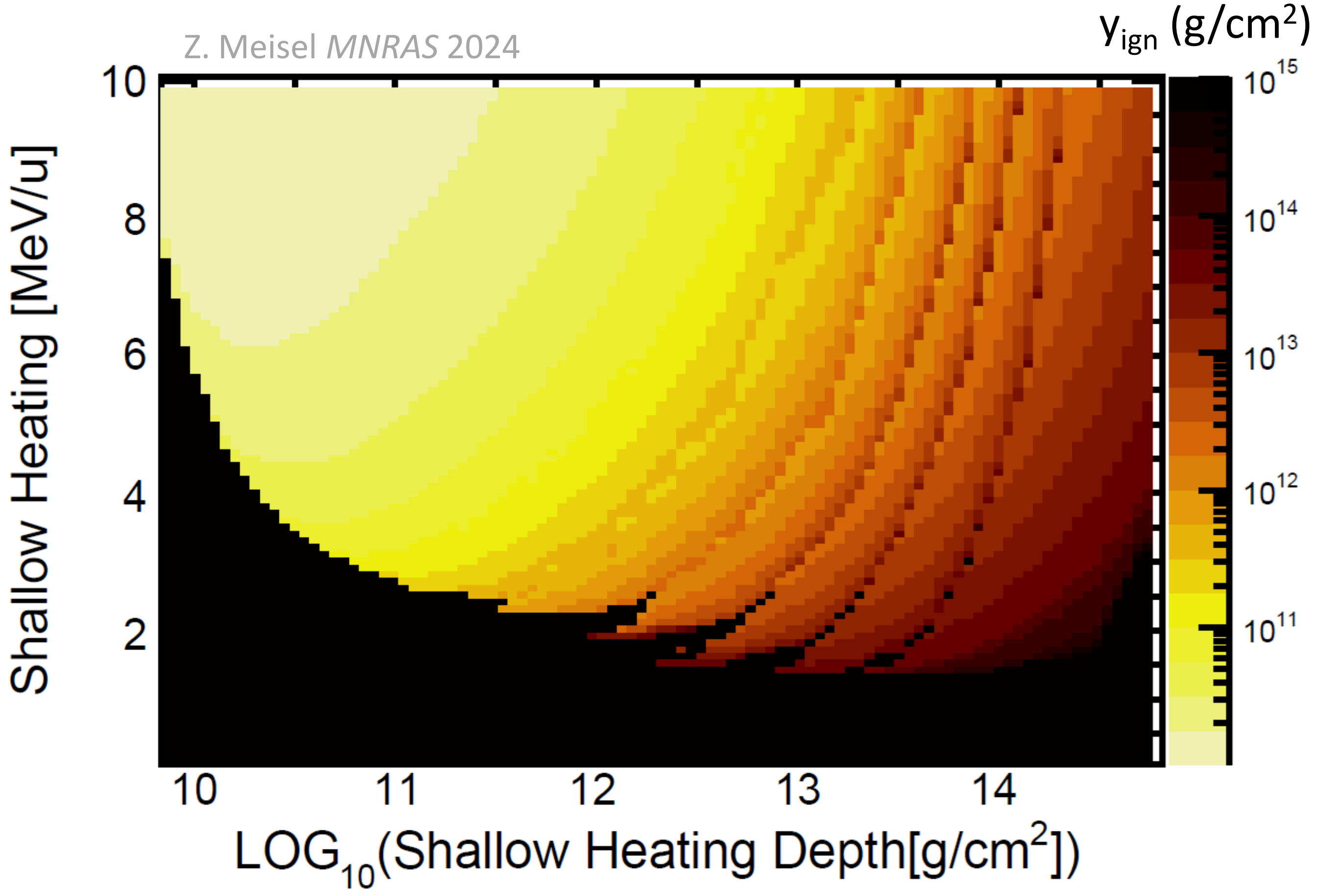
I calculated the carbon ignition depth for six $^{12}C+^{12}C$ rates combined with 161,600 crust thermal profiles from dSTAR models

Parameter	Lower Bound	Upper Bound	Step Size
$\dot{M}$ [$M_{\odot}$ yr^{-1}]	1.75×10^{-9}	1.75×10^{-8}	-
Q_{sh} [MeV u^{-1}]	0.1	10	0.1
$\log(P_{sh}[cgs])$	24	29	0.05
Q_{imp}	4	40	-

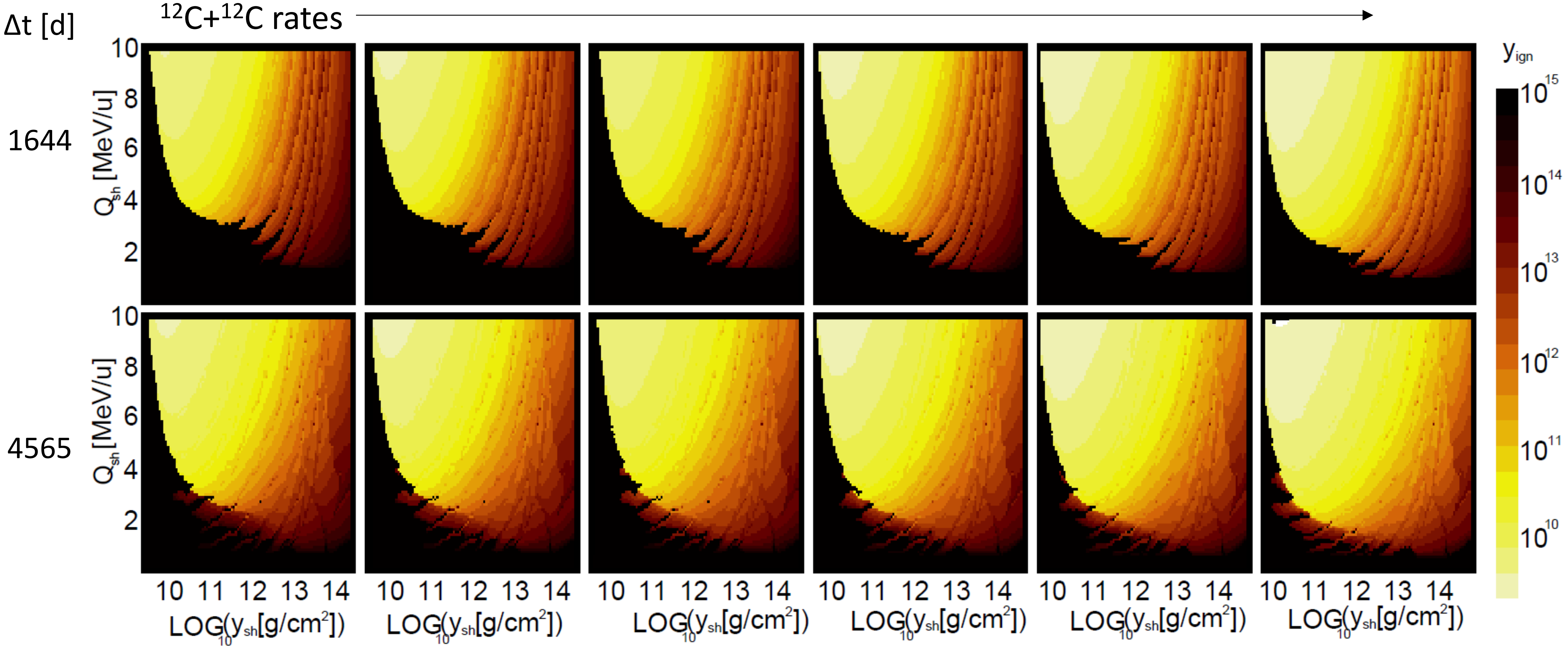
Mode	$X(A)L_{34}$	$\log(P_{urca}[cgs])$
None	0	-
Minimum	4.47×10^{-2}	29.135
Nominal	4.80	29.159
Maximum	5.15×10^{2}	29.184

Δt = 1643.6 d, 4565 d

- - Hindrance
- - THM Corr.
- - Mol. Res.
- - Sao Paulo
- - CC M3Y+Rep
- - THM



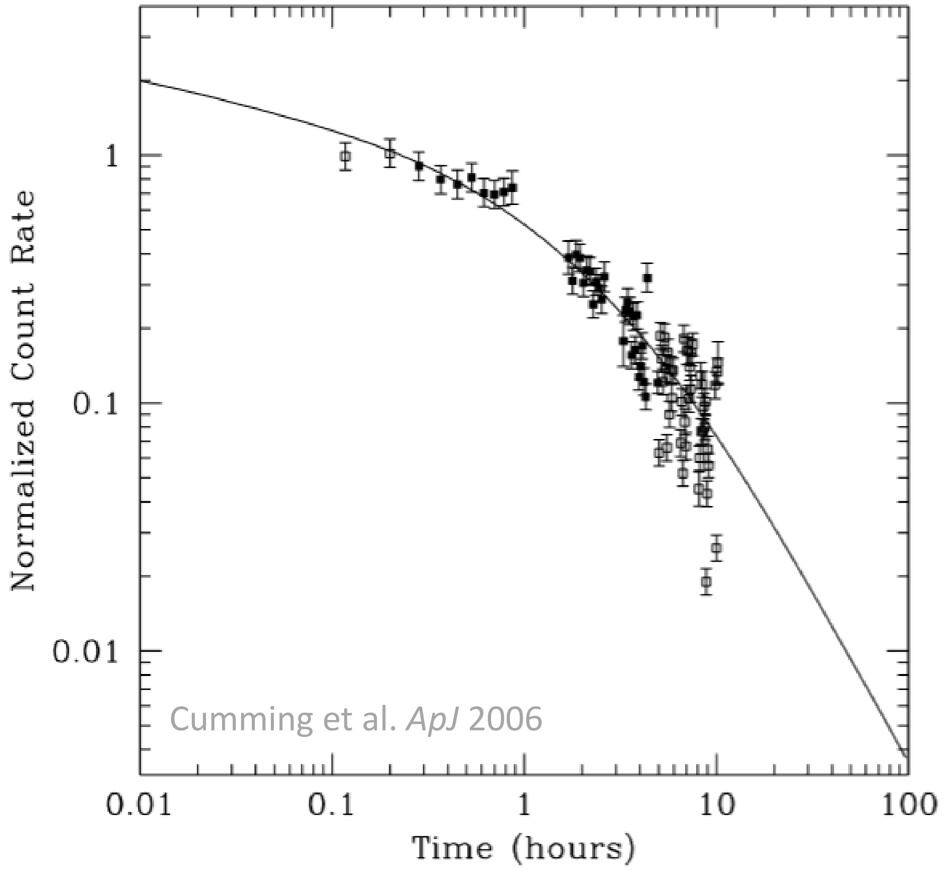
I found that the ignition depths are relatively insensitive to nuclear physics uncertainties ($^{12}C+^{12}C$ rate and crust urca cooling)



Z. Meisel *MNRAS* 2024

$$Q_{\rm imp} = 40,\ \dot{M} = 1.75 \times 10^{-9}\ M_{\odot}\ {\rm yr}^{-1},\ {\rm Urca{=}None}$$

Comparing to observationally-inferred carbon ignition depths provides a constraint on shallow heating



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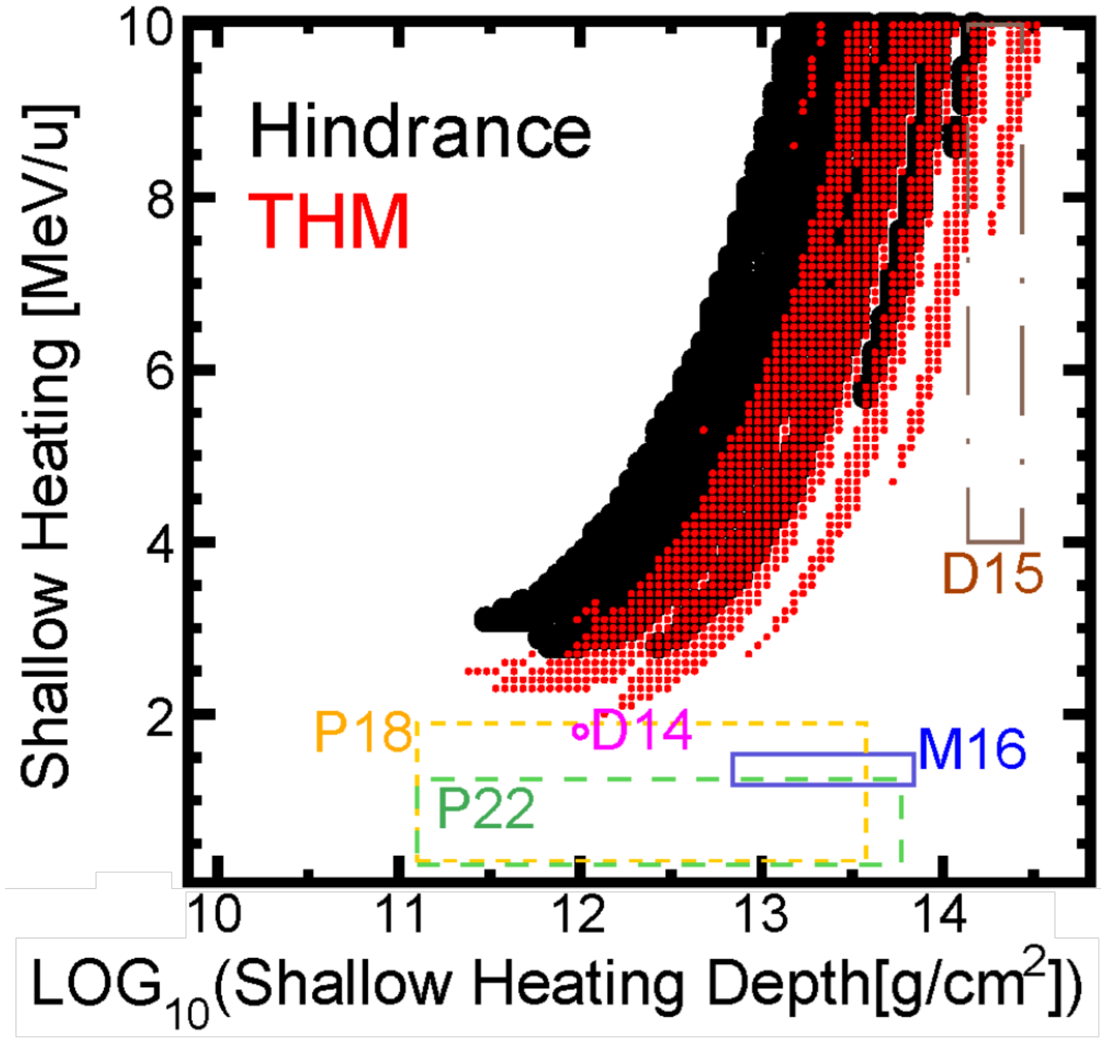
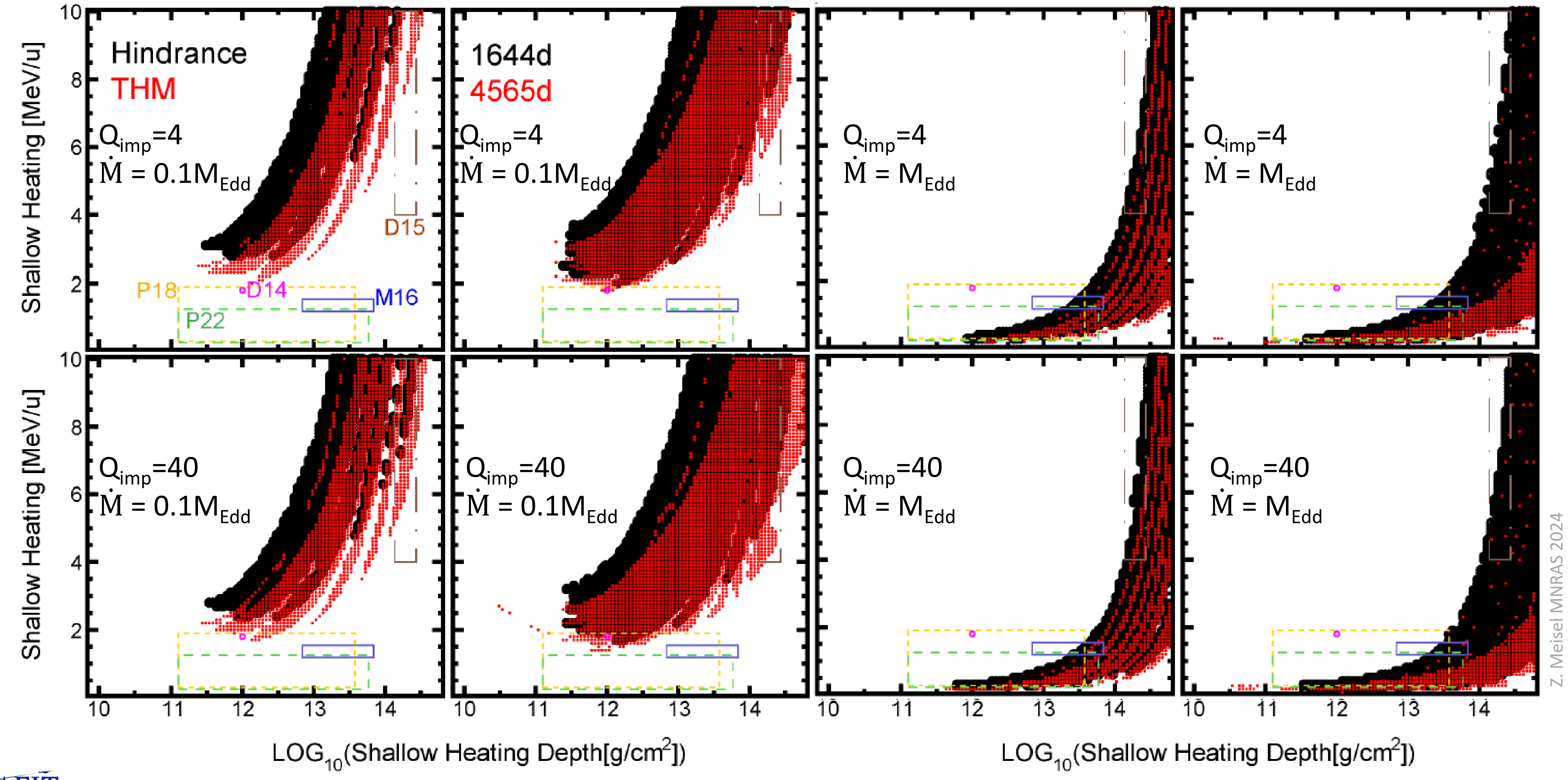


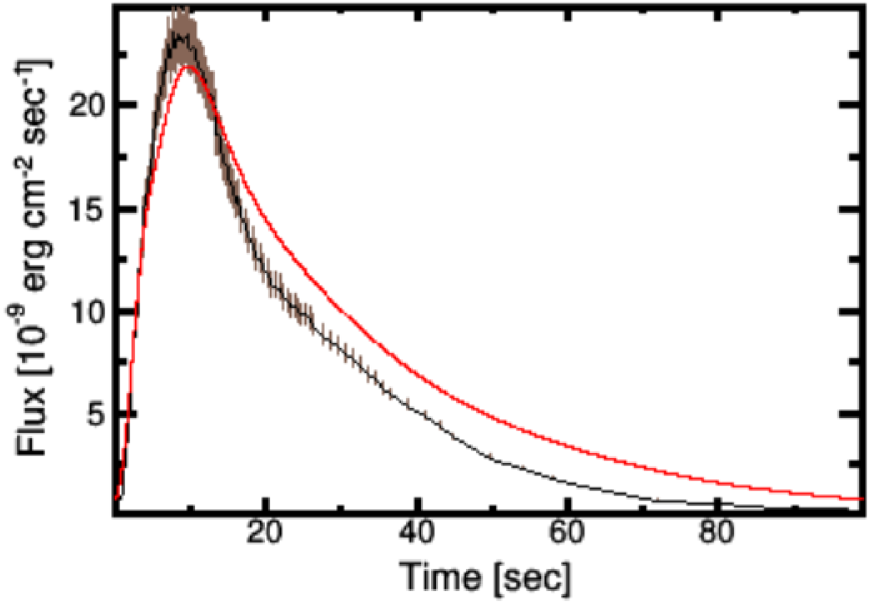
Constraints depend on Q_{imp}, $\dot{M}$, and Δt



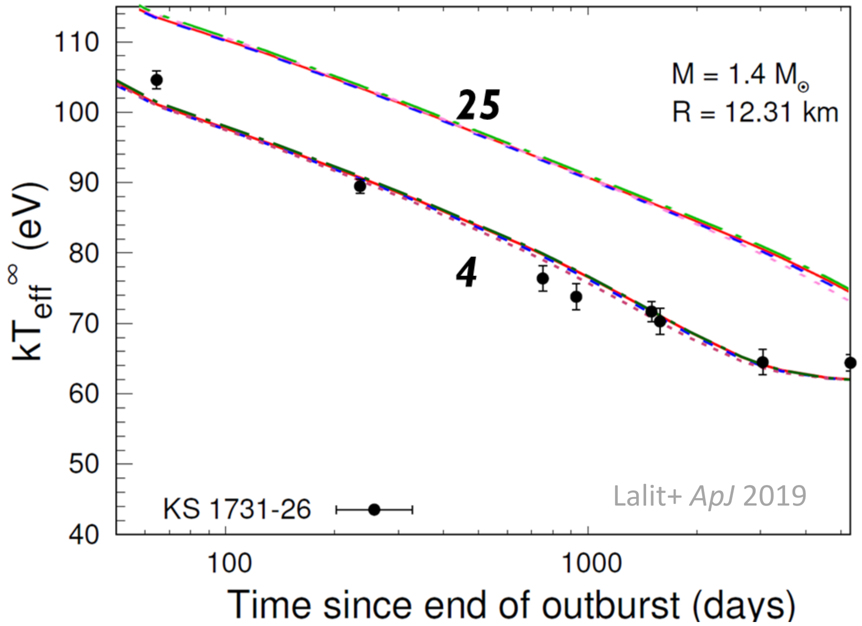
This was a proof of concept. More accurate constraints require:

- Investigating sensitivities to other microphysics, e.g.:
  - *For carbon ignition:* Coulomb logarithm (Roggero & Reddy 2016) & plasma screening (Chugunov & DeWitt 2009)
  - *For crust thermal profile:* NS core direct urca (Dohi et al. 2022) & nuclear crust heating (Fattoyev et al. 2018)
  - *For observational constraints:* pre-burst thermal profile (Keek et al. 2015) & X(^{12}C) (Stevens et al. 2014)
- Consistent multi-observable modeling, e.g. of KS 1731-260, "the hat-trick source":

Bursts



… cooling



… & superbursts