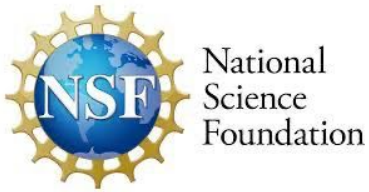
Inferring Properties of a Mysterious Shallow Heat Source in Accreting Neutron Star Crusts

Rahul Jain

Russbach School on Nuclear Astrophysics 2023



This material is based upon work supported by the U.S. National Science Foundation under Award Numbers PHY-1913554, PHY-2209429
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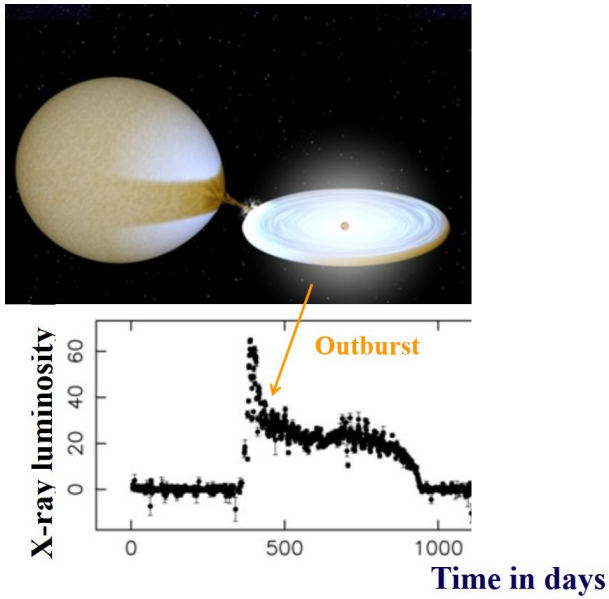
Transient Systems

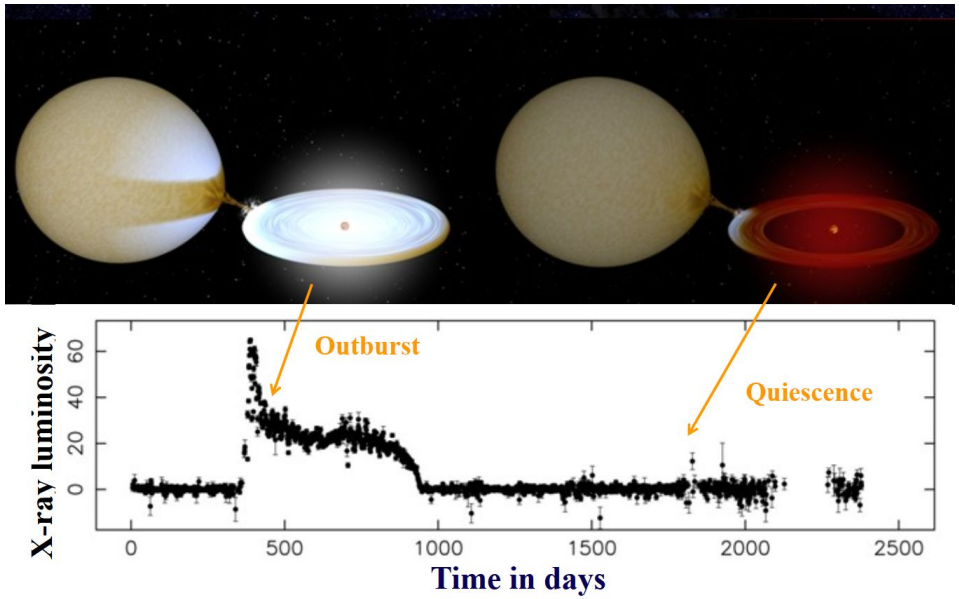


<u>Accretion Outburst:</u>

Rapid Accretion

Bright X-ray Emission

Transient Systems



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Little/No Accretion

Faint X-ray Emission

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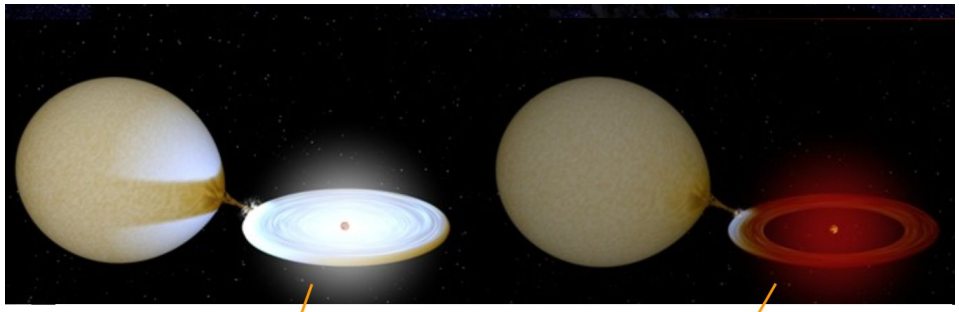

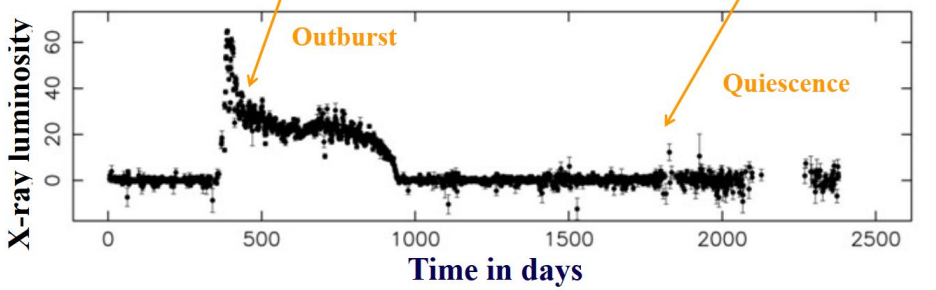

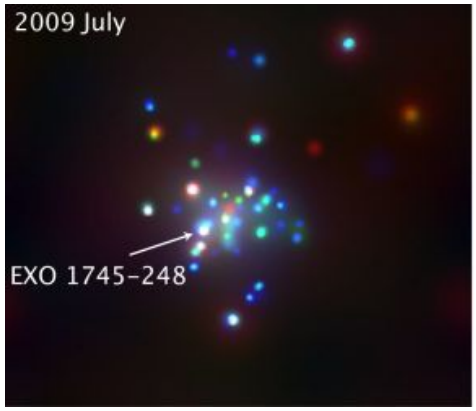

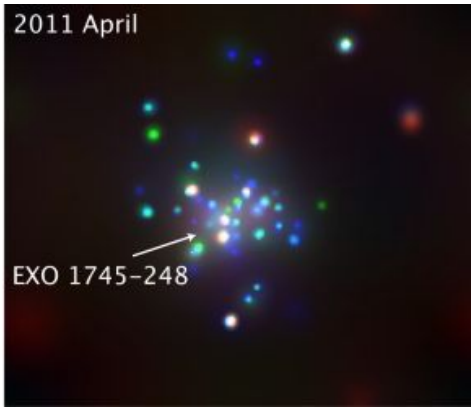

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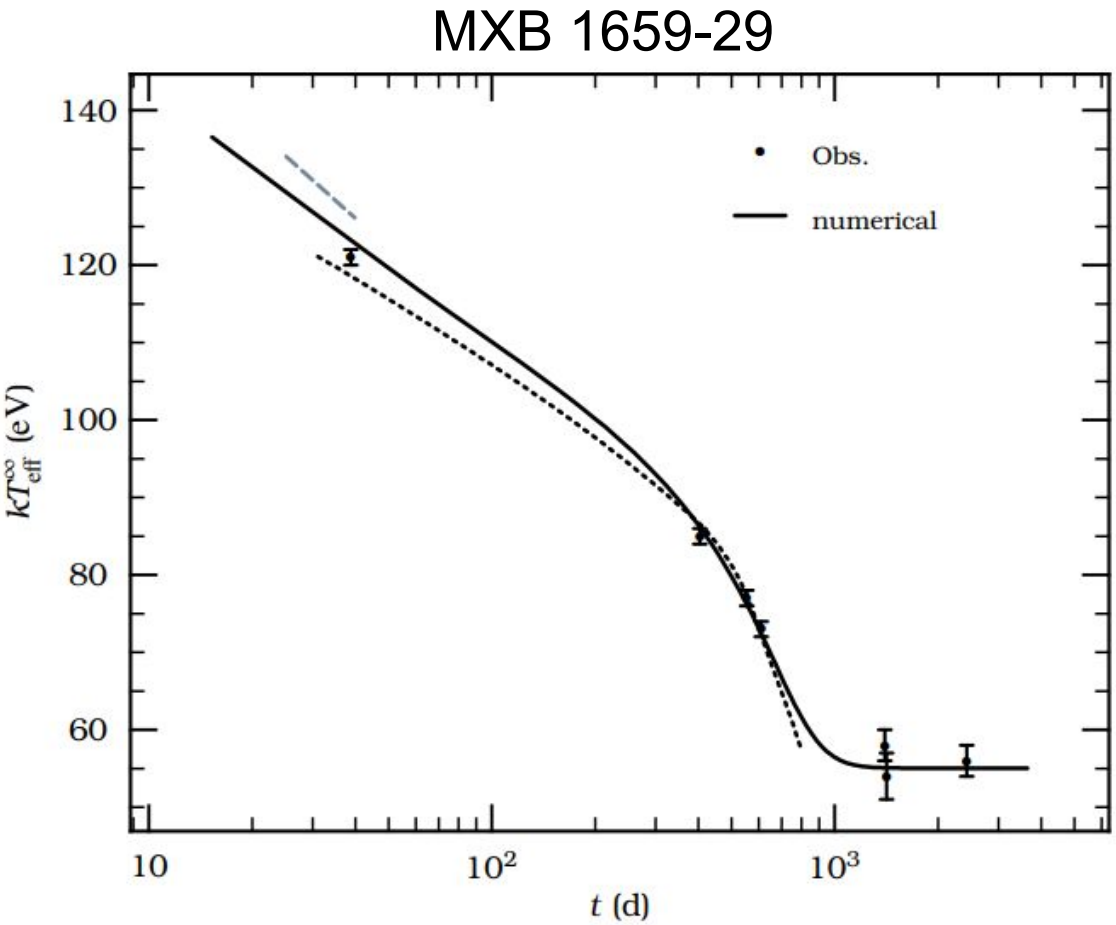
Globular Cluster Terzan 5
with
Chandra X-ray Satellite

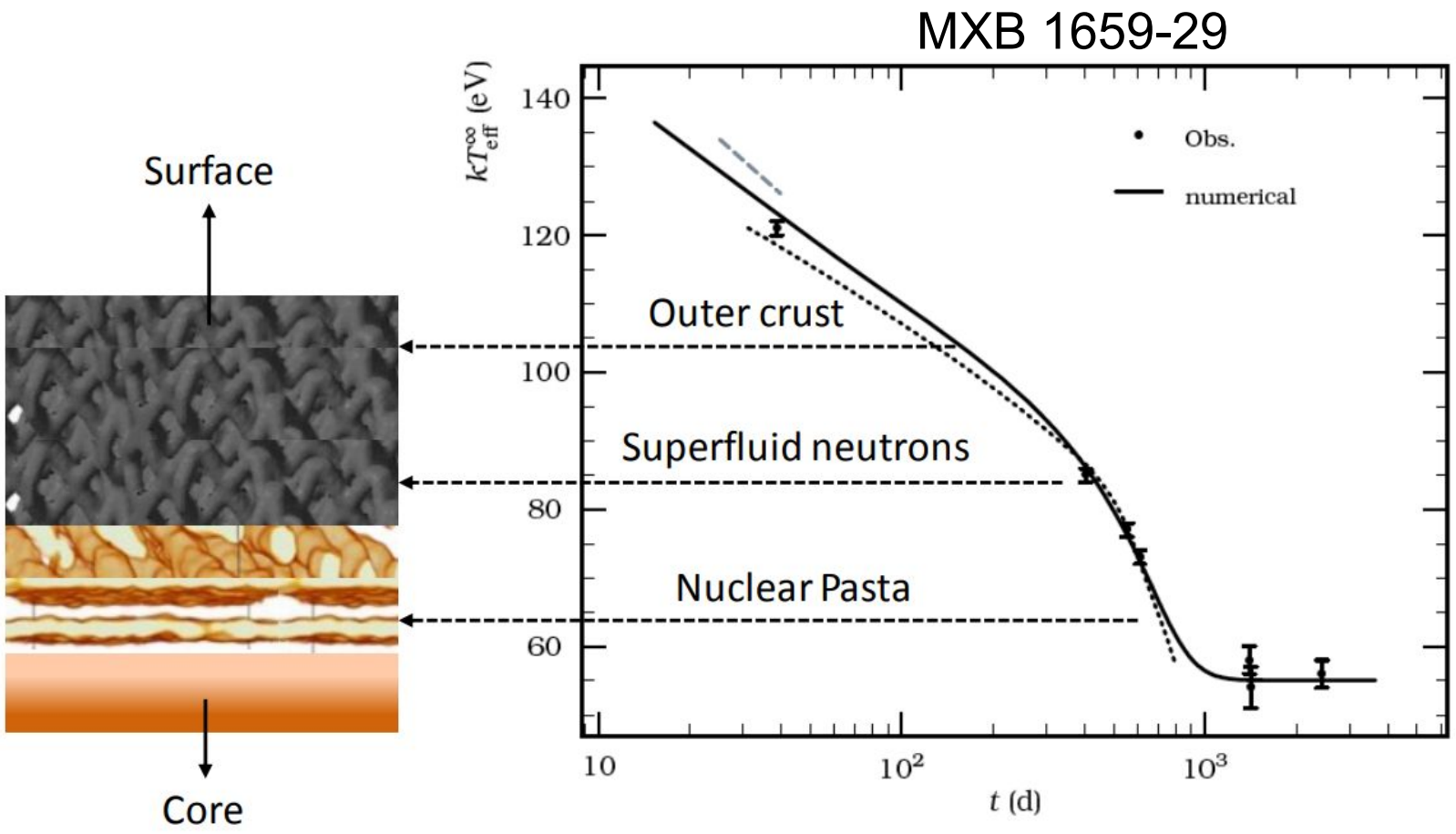
Quiescence Phase

The crust is thermally relaxing during quiescence.



Brown and Cumming 2009 *ApJ* 698 1020

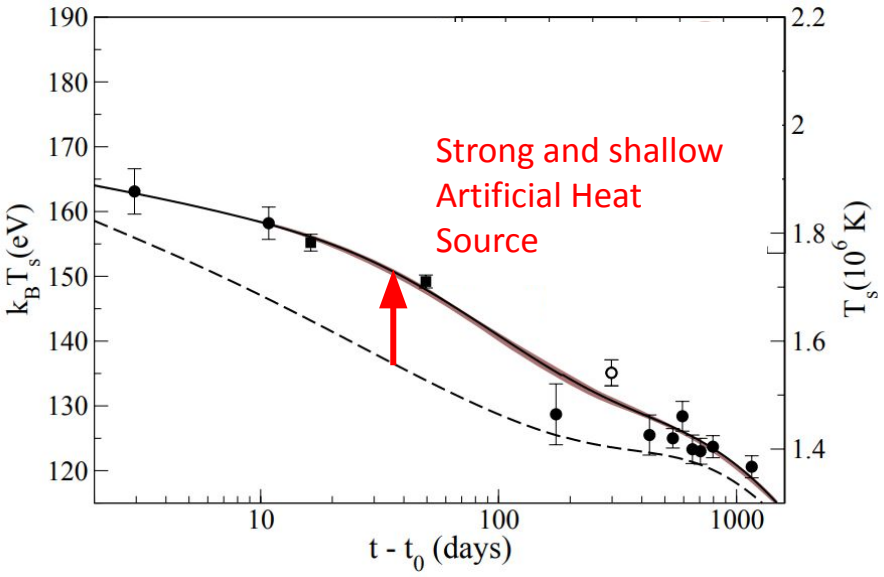
Quiescence Phase



Brown and Cumming 2009 *ApJ* 698 1020
Wei Jia Ong, PhD Thesis, 2018

Extra Heating Requirement

XTE J1701-462



A Turlione et al., A&A 577, A5 (2015)

Artificial heat source has to be accounted for to match models to observations for almost all systems.

Shallow Heat Source

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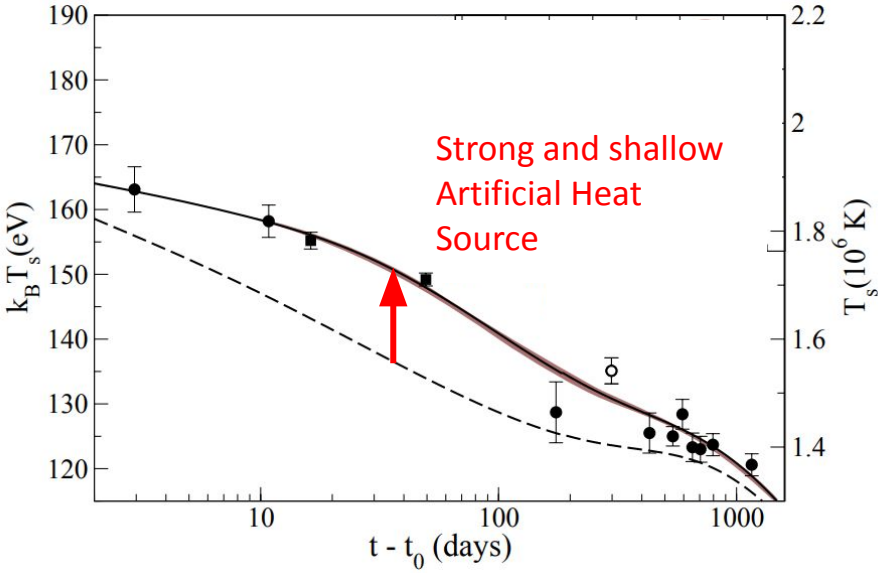
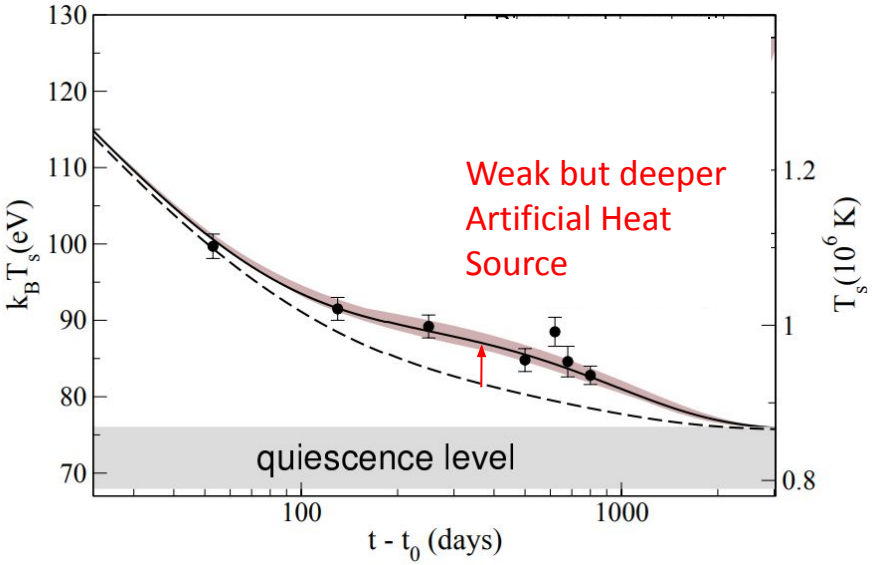


IGR J17480-2446



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Shallow Heat Source - Possible Origins

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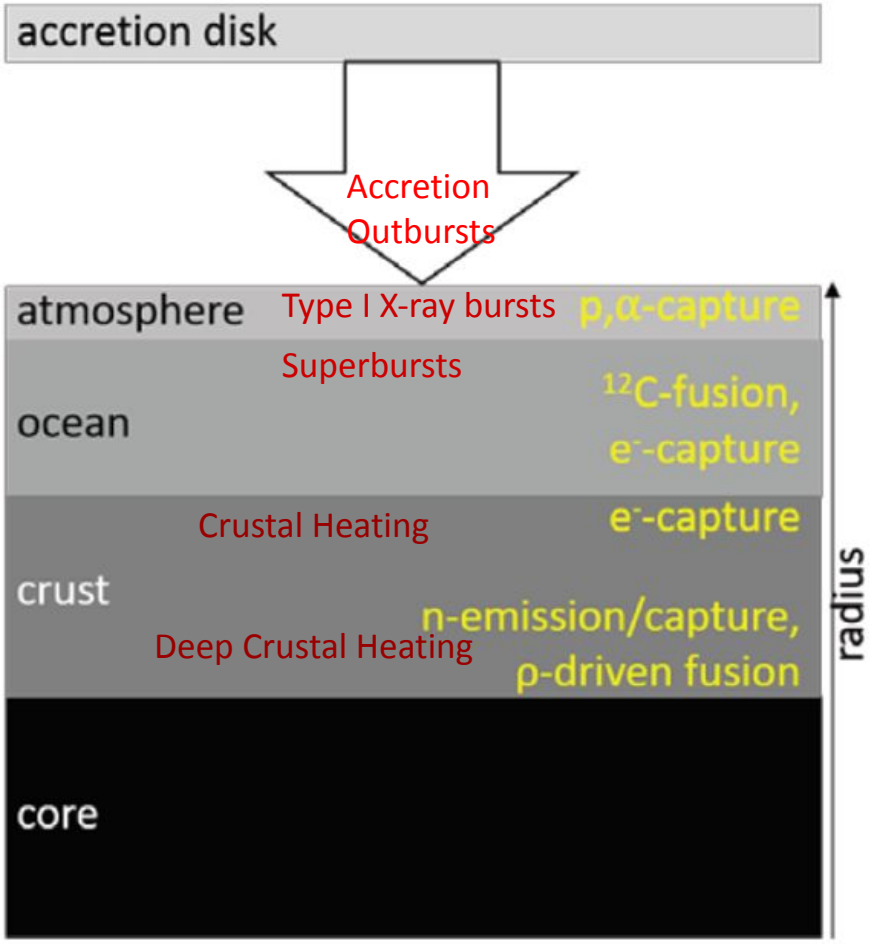
May other propositions like

- Convective mixing (Horowitz et al. 2007)
- Excitation of gravitational modes (Inogamov and Sunoyev, 2010)
- Hyperbursts powered by O-Ne explosive fusion (Page et al. 2022)

Outburst Phase

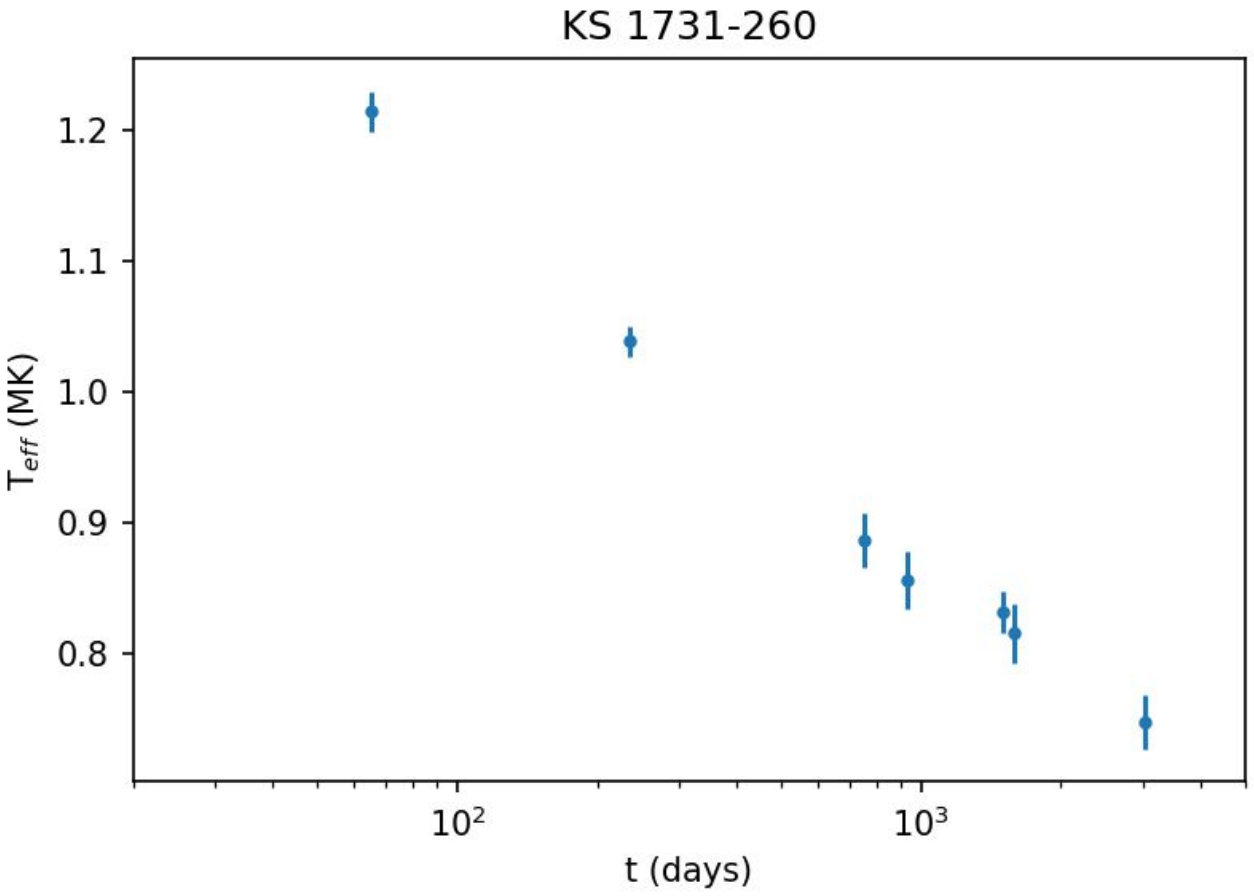


Nuclear reactions heat the crust during outburst.

Xnet Reaction Network
(W. R. Hix from ORNL)

Adapted from Z. Meisel

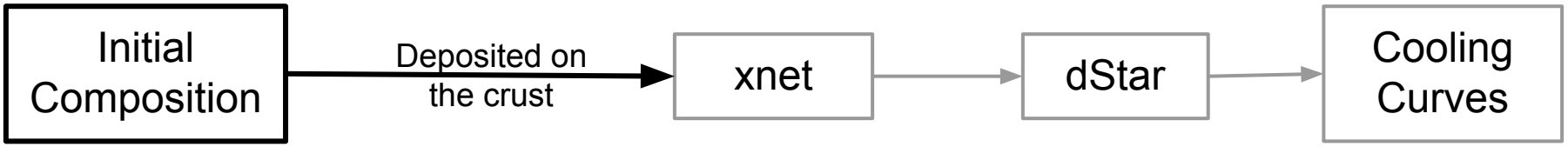
KS 1731-260

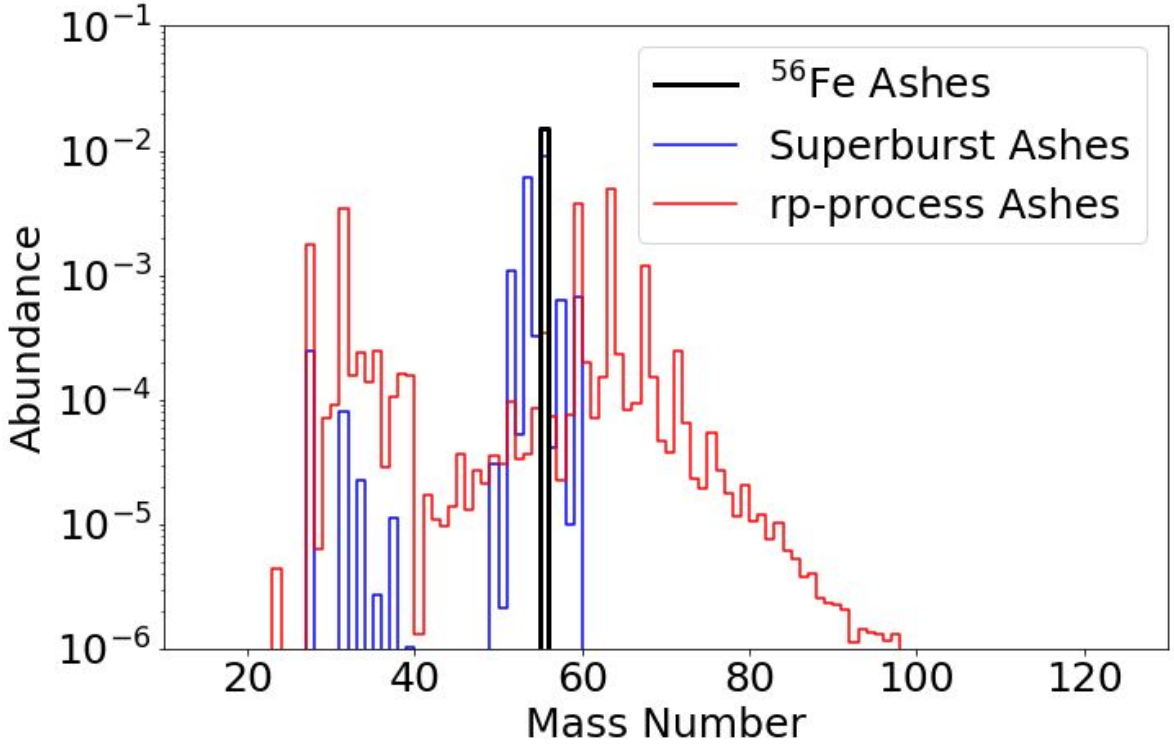


- Observed with Chandra X-ray telescope.
- M = 1.6 M_{sun}
- R = 10.42 km
- A = 10^{17} g/cm^2
- T = 4383 days

Muno et al. 2000
Brown and Cumming 2009
Meritt et al. 2016

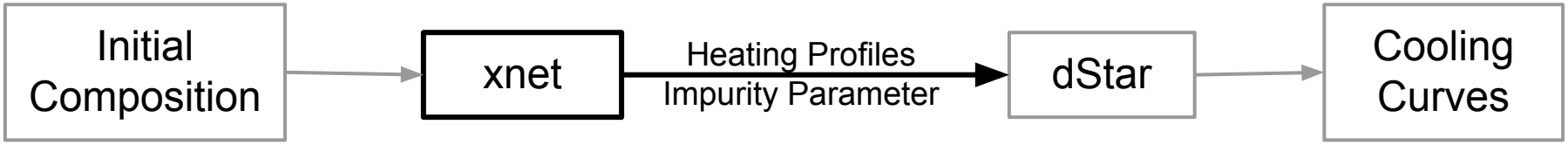
Initial Composition

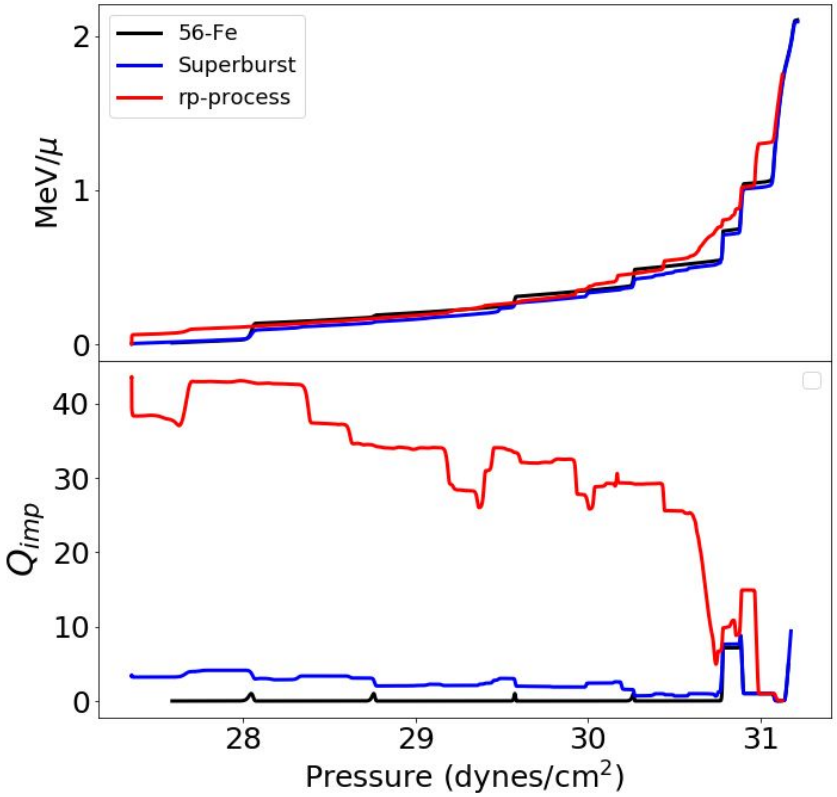




L Keek et al. (2012)
Woosley et al. (2004)
R Cyburt et al. (2016)

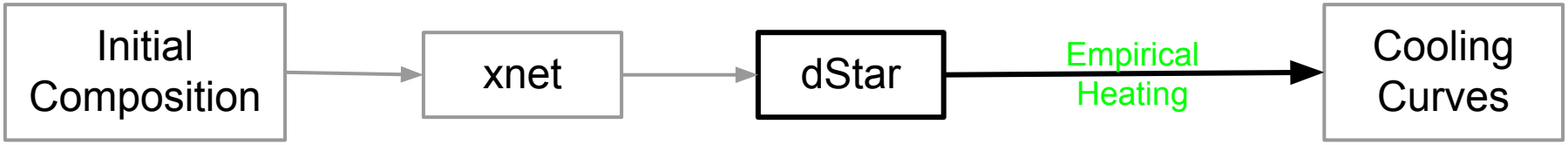
xnet

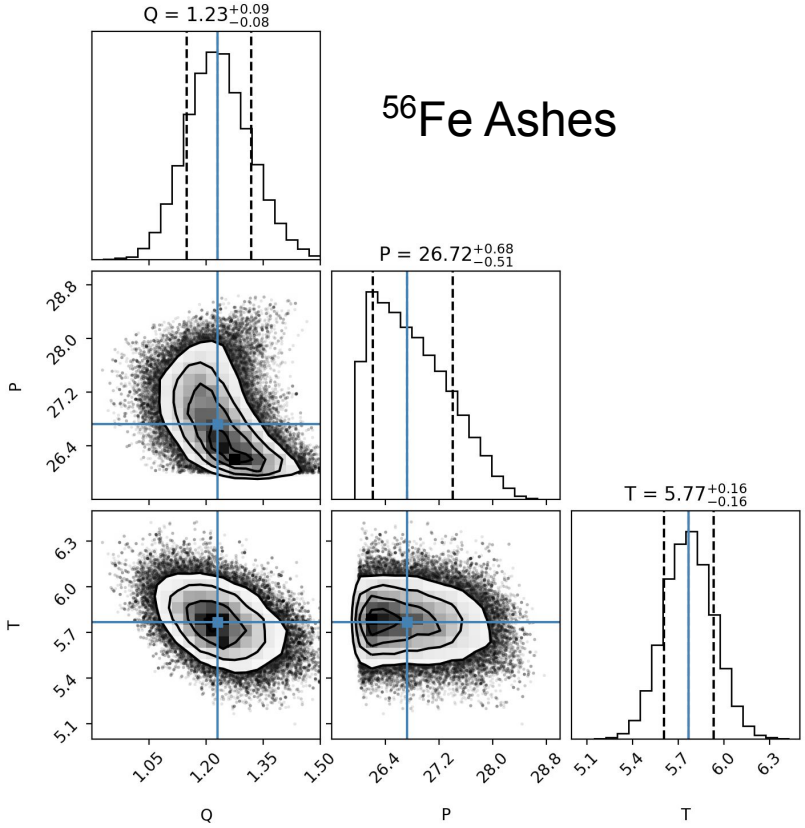




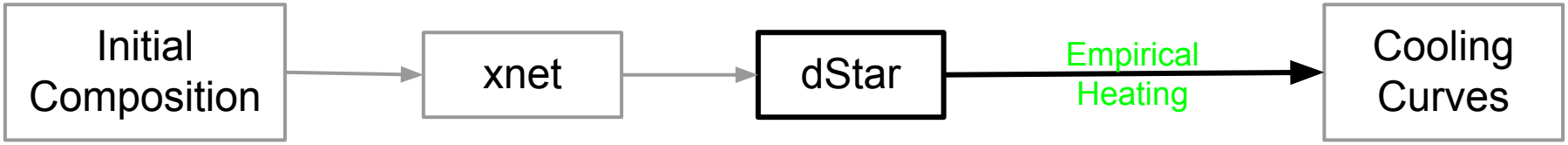
The huge difference in impurity parameter affects the conductivity of the crust.

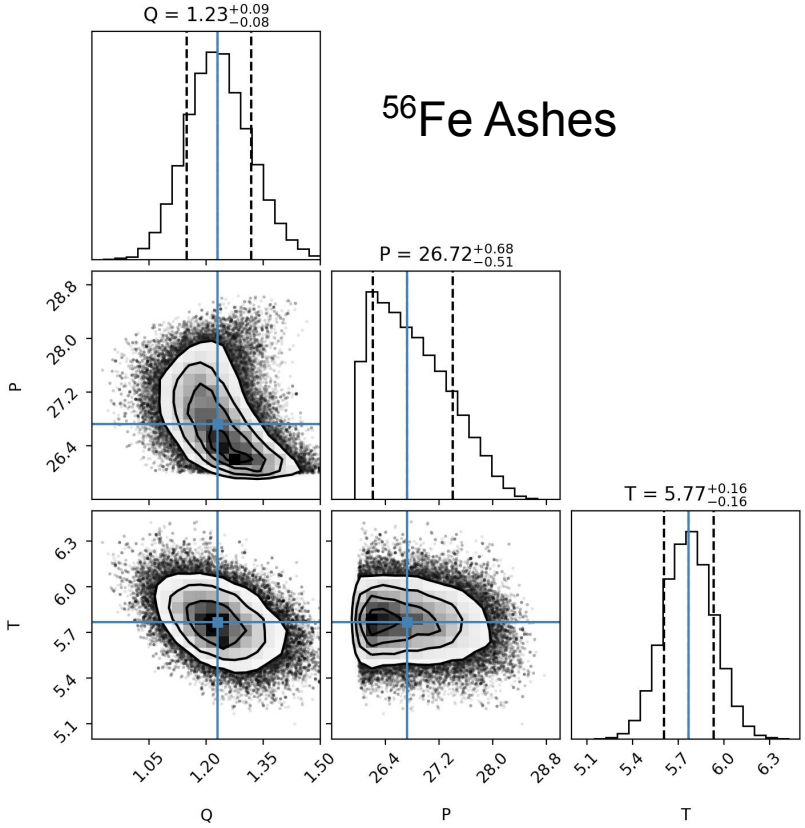
dStar


Initial Composition
xnet
dStar
Empirical Heating
Cooling Curves


$Q = 1.23^{+0.09}_{-0.08}$
^{56}Fe Ashes
$P = 26.72^{+0.68}_{-0.51}$
$T = 5.77^{+0.16}_{-0.16}$
Q
P
T

dStar





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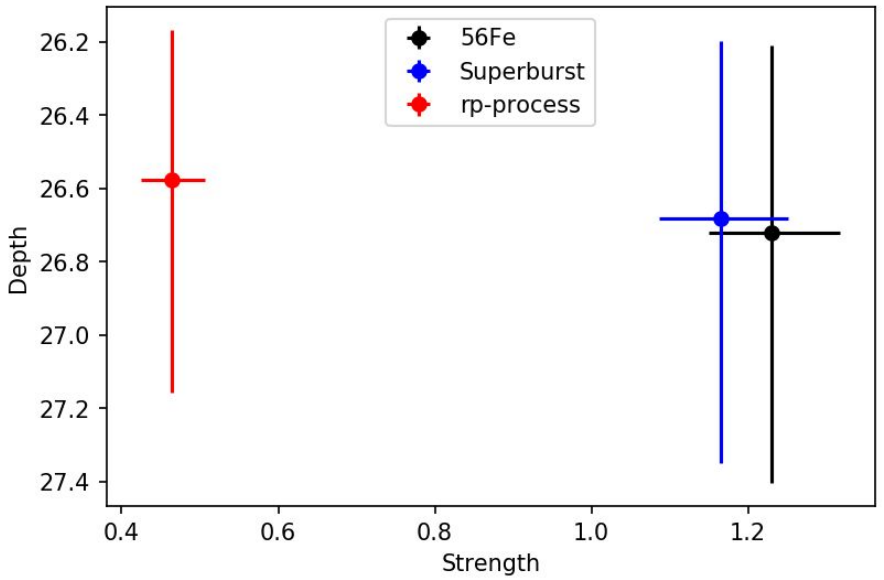
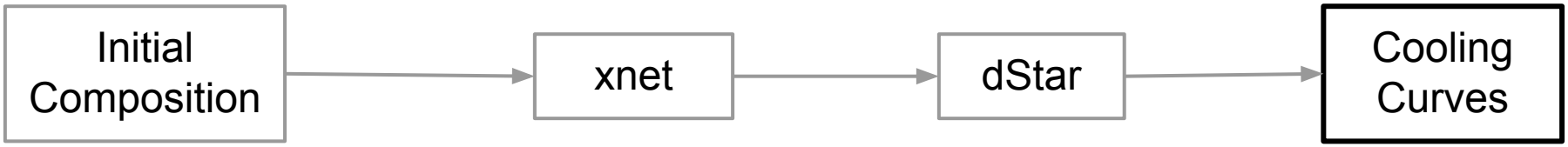
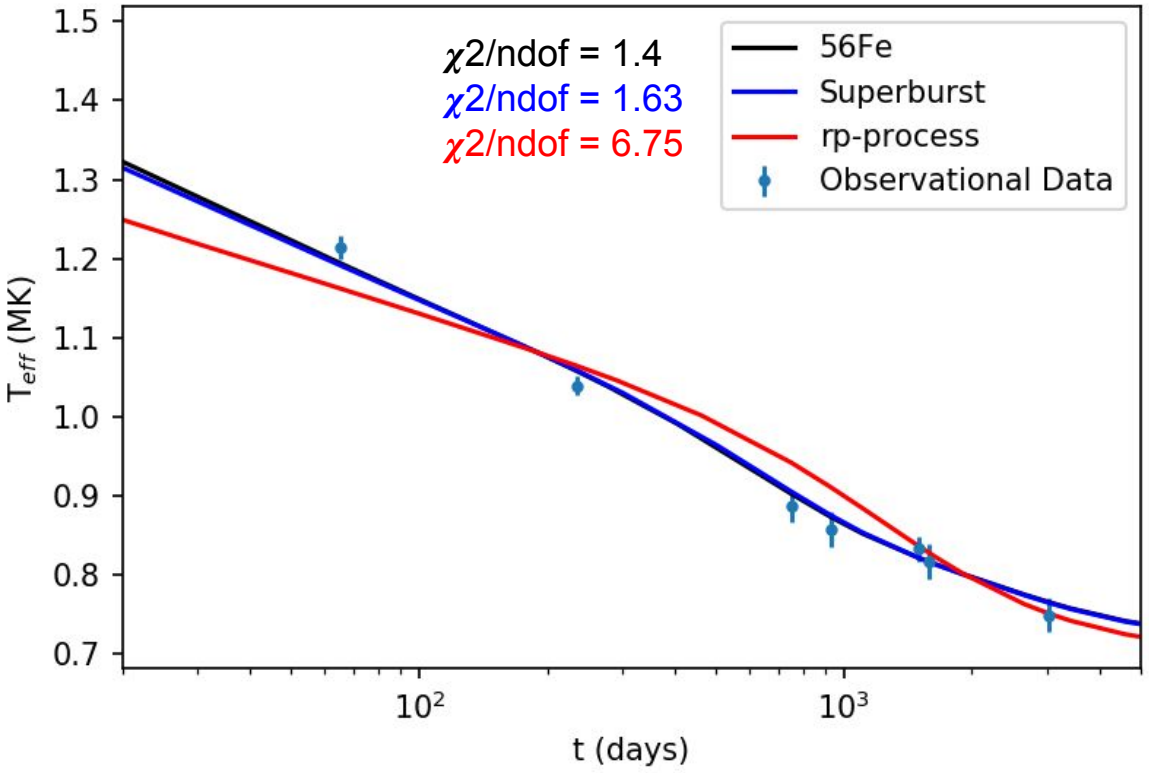
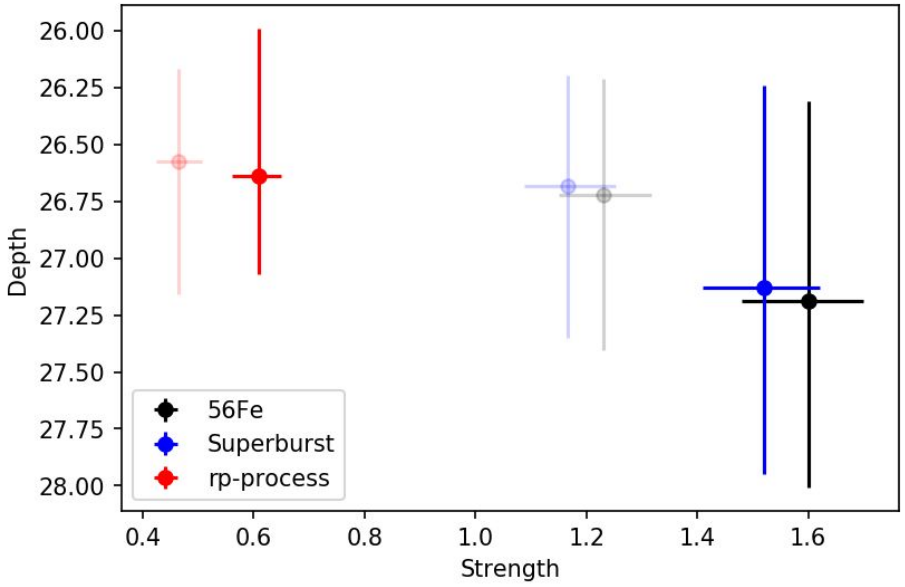


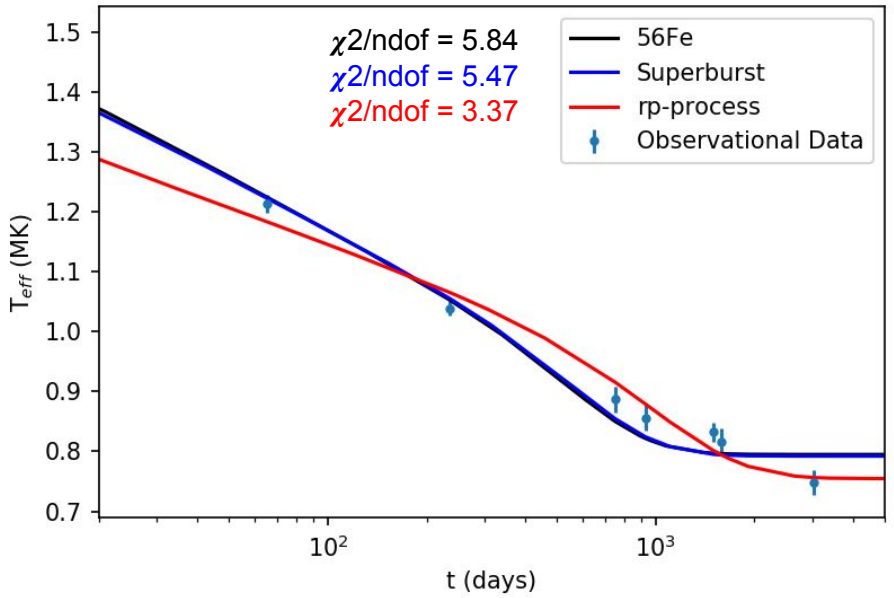
Cooling Curves





Low Impurity in Pasta





Low impurity nuclear pasta fits worse for all compositions.
This is an evidence for high impurity of nuclear pasta.

Conclusions

- Detailed composition of the neutron star crust from realistic nucleosynthesis calculations can now be coupled to thermal evolution codes.

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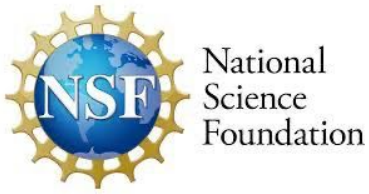
- The inferred properties of a mysterious shallow heat source strongly depend on the previous nuclear burning stages.
- The accreted material for KS 1731-260 is likely to be re-processed with superbursts.
- Cooling curve observations of quasi-persistent transients provide evidence for high impurity scattering in nuclear pasta.

Thank you!

Collaborators:	Hendrik Schatz, Edward F Brown, Rita Lau
xnet:	William Raph Hix
dStar:	Edward F Brown
EC/β^- rates:	Sanjib S Gupta, Peter Möller, Wei-Jia Ong
Fusion rates:	Mary Beard, Anatoli V Afansajev, L C Chamon, L R Gasques, Michael Wiescher
Initial Comp:	Laurens Keek



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