SFB 1245: Nuclei: From fundamental Interactions to Structure and Stars

TECHNISCHE UNIVERSITÄT DARMSTADT

B01: Electroweak interactions in nuclei and matter

PIs: Gabriel Martínez-Pinedo and Achim Schwenk

SFB 1245

People

Postdocs

- Kyle Wendt (Lawrence Fellow, LLNL)
- Sebastian König

Doctoral Researchers

- Alex Bartl, at present Svenja Greif
- Dag Fahlin Strömberg

Master Theses:

- Svenja Greif, Jonas Keller, Sabrina Schäfer, Marc Schönborn, Christian Schwebler

Bachelor Theses:

- Steven Bilaj, Malte Cordts, Mirko Plößer

Publications:

17 publications in first period **(1 Nature Phys., 5 PRL)**,
4 Editors' suggestions, 2 press releases

Key Publications

Discrepancy between experimental and theoretical β-decay rates resolved from first principles

P. Gysbers, et al, Nat. Phys. (2019).

Equation of state sensitivities when inferring neutron star and dense matter properties

S. K. Greif, et al, Mon. Not. R. Astron. Soc. 2019

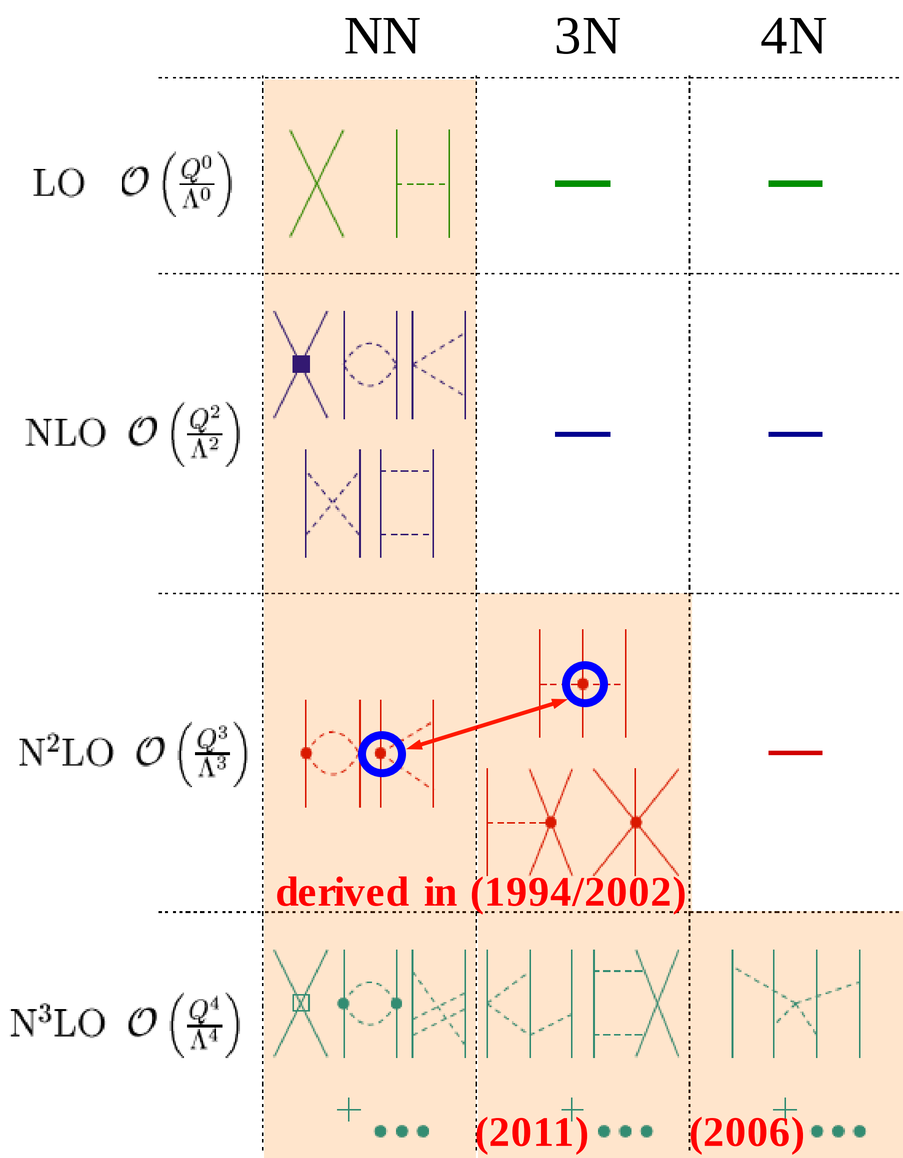
Thermonuclear supernova triggered by electron captures

O. S. Kirsebom, et al, submitted to Science

Fingerprints of Heavy-Element Nucleosynthesis in the Late-Time Lightcurves of Kilonovae

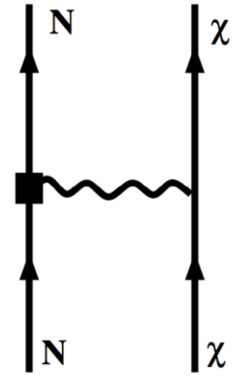
M.-R. Wu, et al, Phys. Rev. Lett. 122, 062701 (2019).

Chiral EFT for coupling to external sources

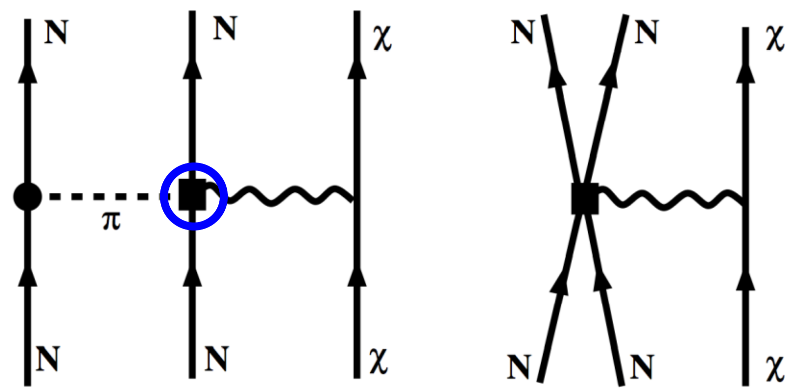


example: axial-vector currents

one-body currents at Q^0 and Q^2



\+ two-body currents at Q^3



same couplings in forces and currents!

Chiral EFT for electroweak currents

consistent electroweak one- and two-body (meson-exchange) currents

magnetic moments in A=3

Hernandez, Bacca (MZ),
Seutin, Hebeler, König, AS

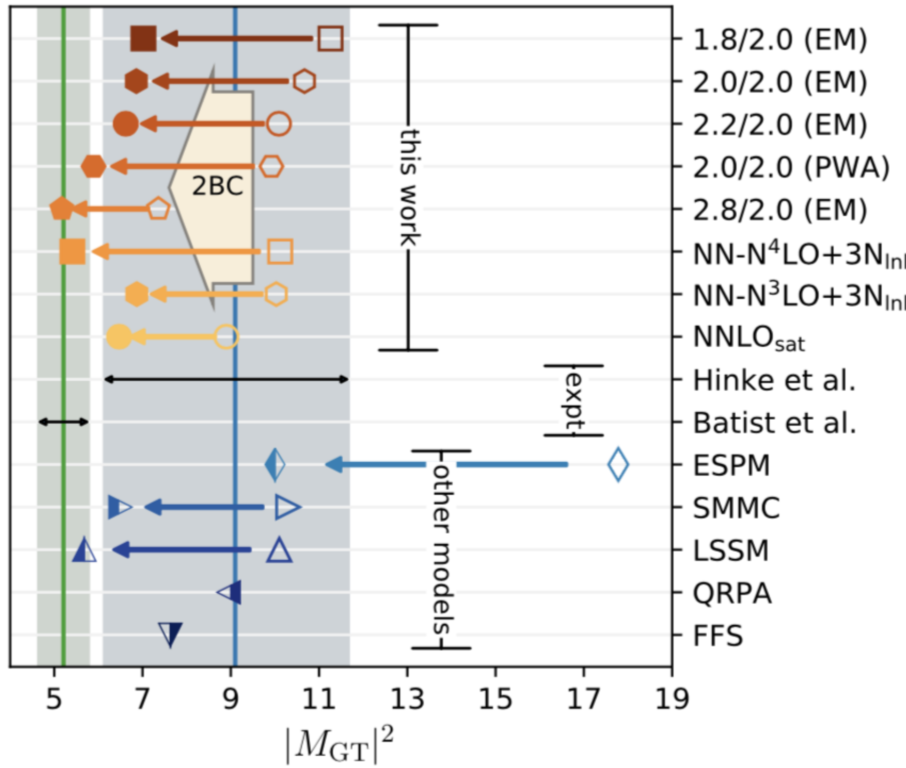
	^{3}H	^{3}He	%Diff from Exp
$\mu_{\mathrm{LO}}^{[1]}$	2.622	-1.783	~12-16%
$\mu_{\mathrm{LO}}^{[1]} + \mu_{\mathrm{Intrinsic}}^{[2]}$	2.816	-1.973	~5-7%
$\mu_{\mathrm{LO}}^{[1]} + \mu_{\mathrm{NLO}}^{[2]}$	**2.849(7)**	**-2.006(6)**	**~4-6%**
μ_{Exp}	**2.979**	**-2.128**	-

application to ^{6}Li with A02

Gayer et al., in prep.

Gamow-Teller beta decay of ^{100}Sn

Gysbers, …, AS, Wendt, Nature Phys. (2019)

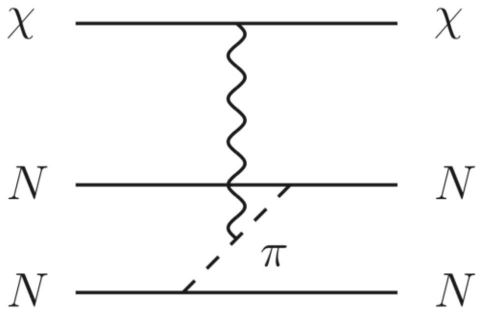


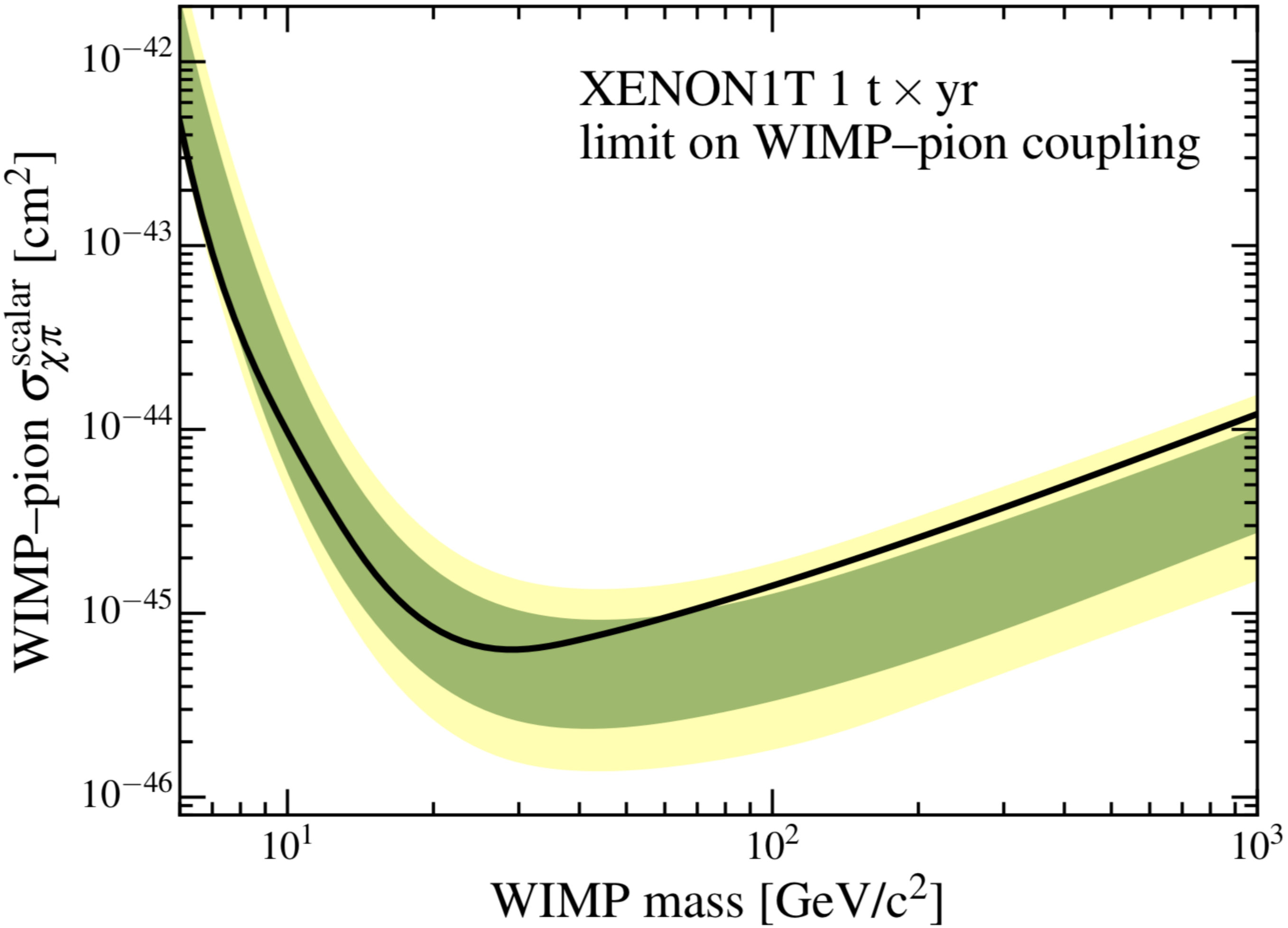
two-body currents are key for quenching puzzle of beta decays

First limits for WIMP-pion interactions

in collaboration with XENON1T Aprile et al., PRL (2019)

based on chiral EFT for WIMP-nucleon/pion interactions

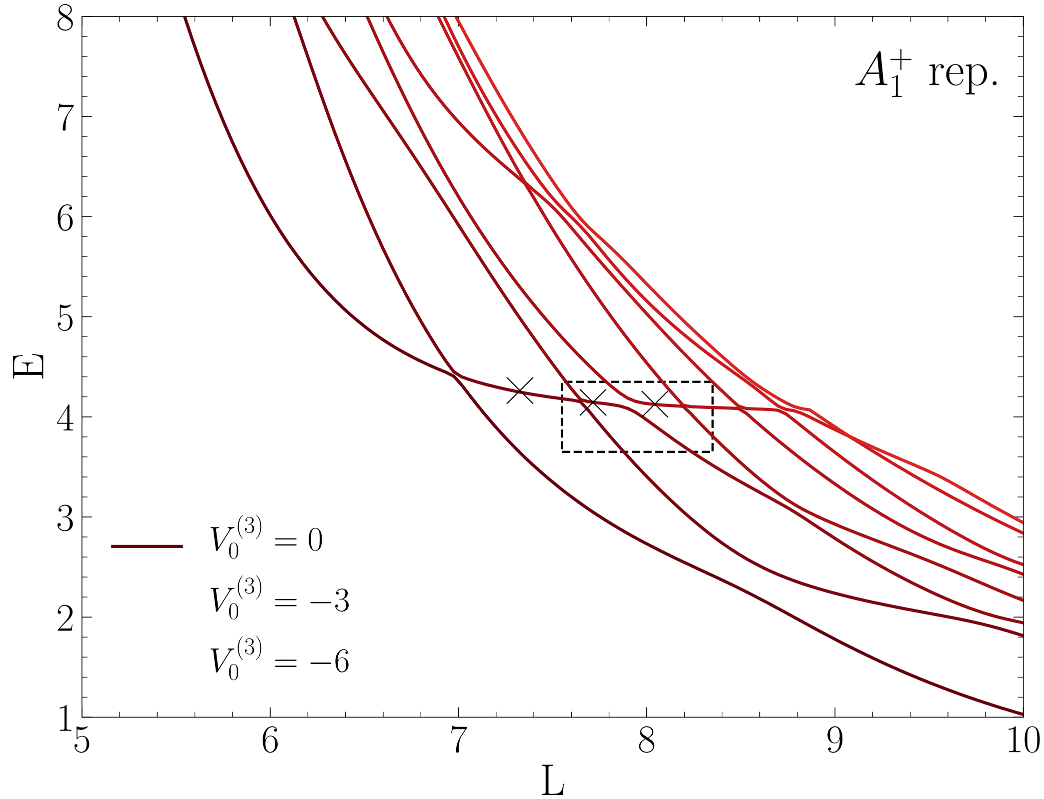




Resonance properties from finite volume König et al., PRC (2018) with A02

resonance energy from avoided level crossings in 3-body spectrum

resonance width from spacing between avoided level crossings



genuine 3-body resonance probed by varying short-range 3-body potential

EOS impact on core-collapse supernova simulations

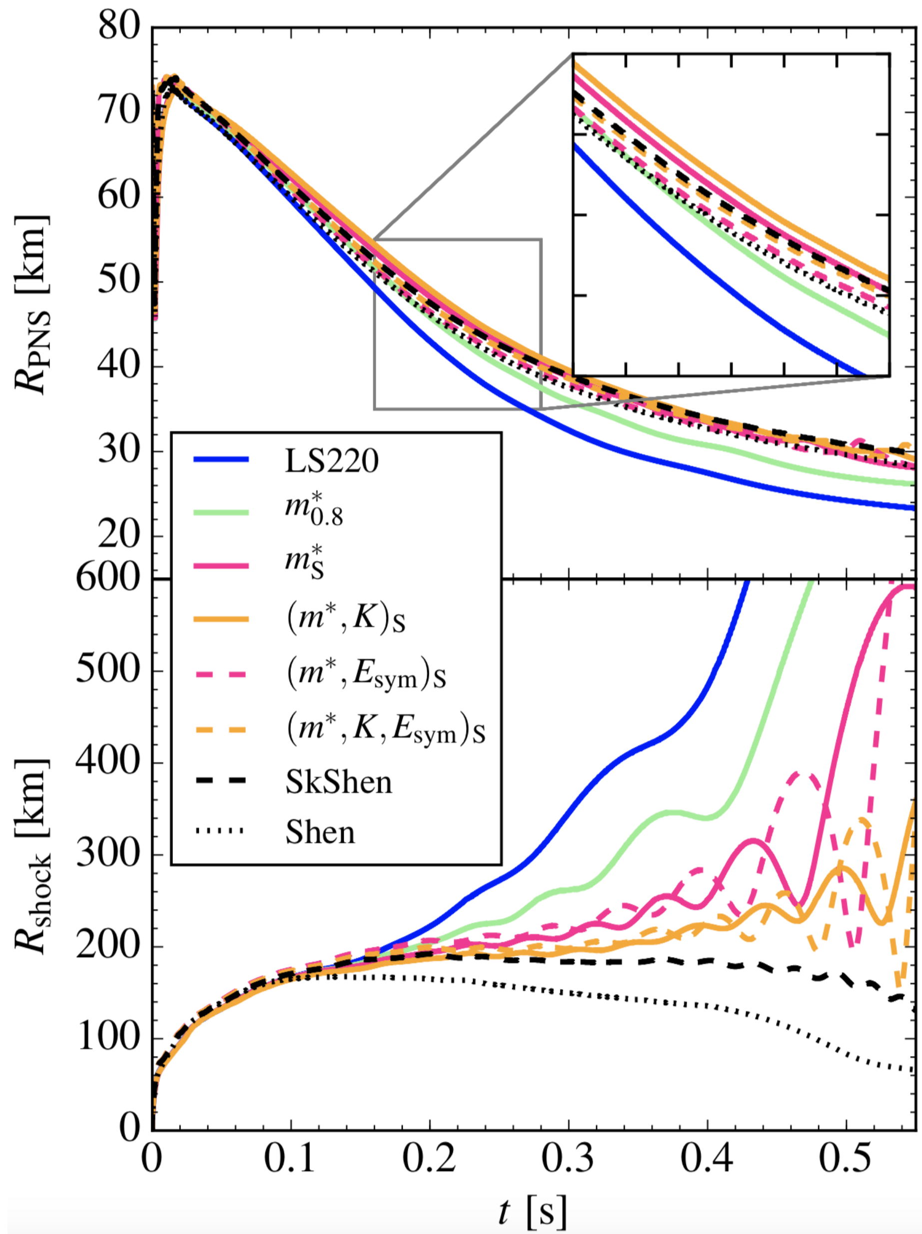
Yasin, Schäfer, Arcones, AS, 1812.02002 with B06

constructed EOS that systematically vary nuclear matter properties between LS and Shen et al. EOS

	m^*/m	K	E_{sym}	L	n_0	B
LS220	1.0	220	29.6	73.7	0.155	16.0
Shen	0.634	281	36.9[a]	110.8	0.145	16.3
Theo.	0.9(2)	215(40)	32(4)	51(19)	0.164(7)	15.86(57)

thermal contributions/m* are key for proto-neutron star contraction

faster contraction aids supernova shock to more successful explosion

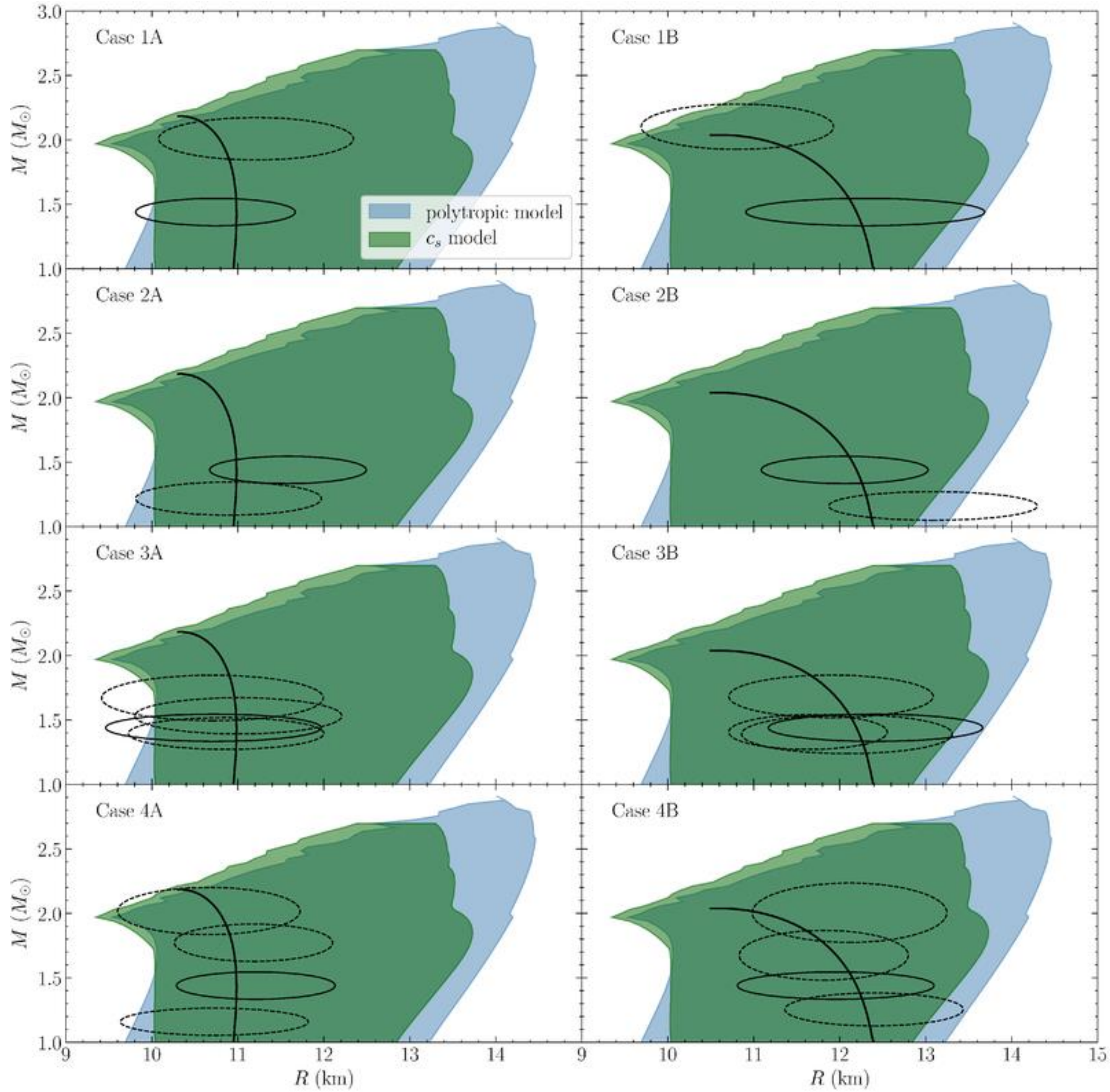


Impact on inferring EOS and neutron star properties

Greif, Raaijmakers, Hebeler, AS, Watts, MNRAS (2019) with B05

based on chiral EFT + polytropic or new speed-of-sound extrapolation

consider different scenarios from observations (1A-4B)



Impact on inferring EOS and neutron star properties

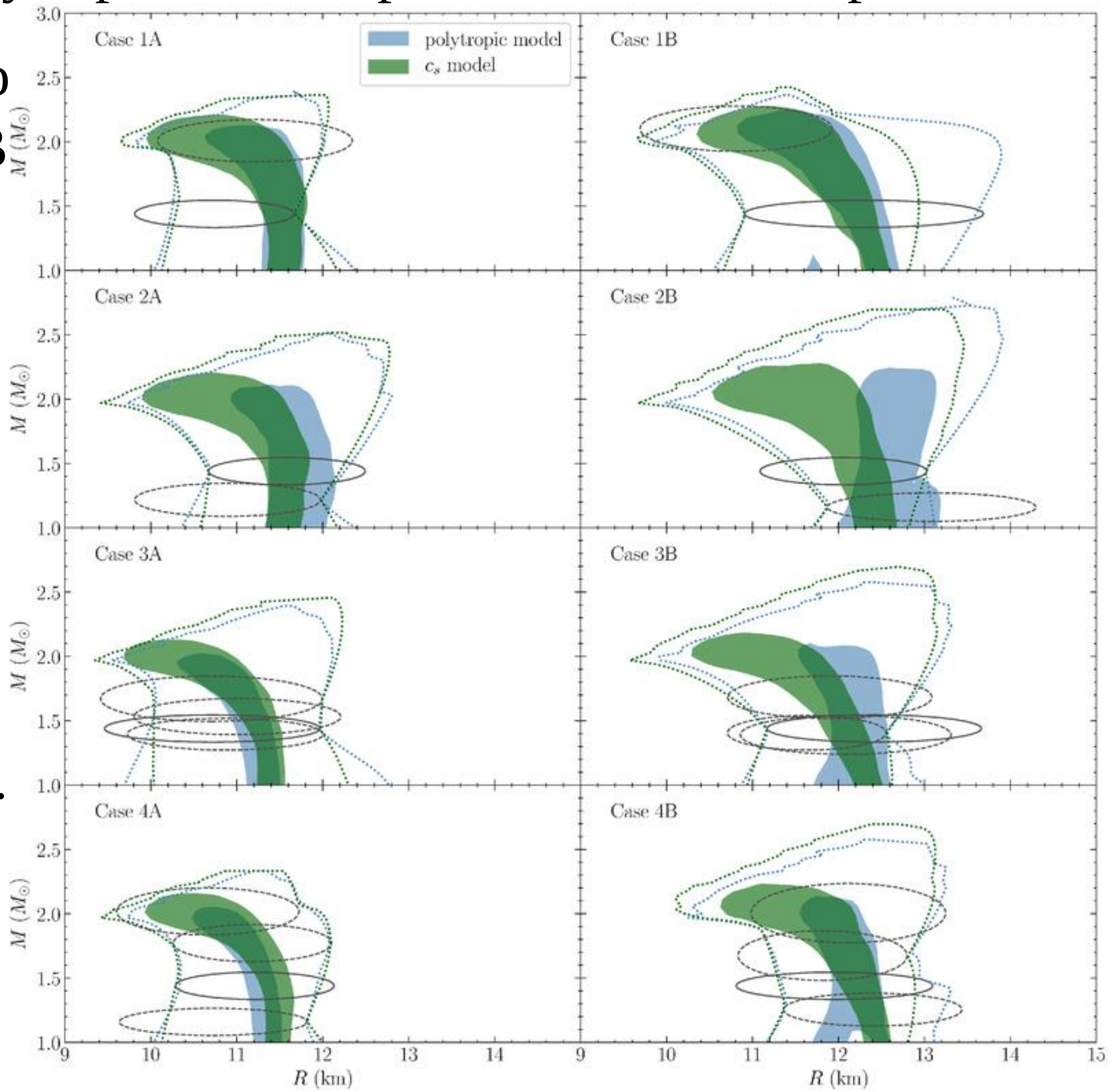
Greif, Raaijmakers, Hebeler, AS, Watts, MNRAS (2019) with B05

based on chiral EFT + polytropic or new speed-of-sound extrapolation

consider different scenario from observations (1A-4B

give remarkably narrow ranges ~11-12km, based on Bayesian inference

identifies important EOS sensitivities neglected in astro extractions (LIGO/VIRGO, NICER,..



What is the final outcome of intermediate mass stars?

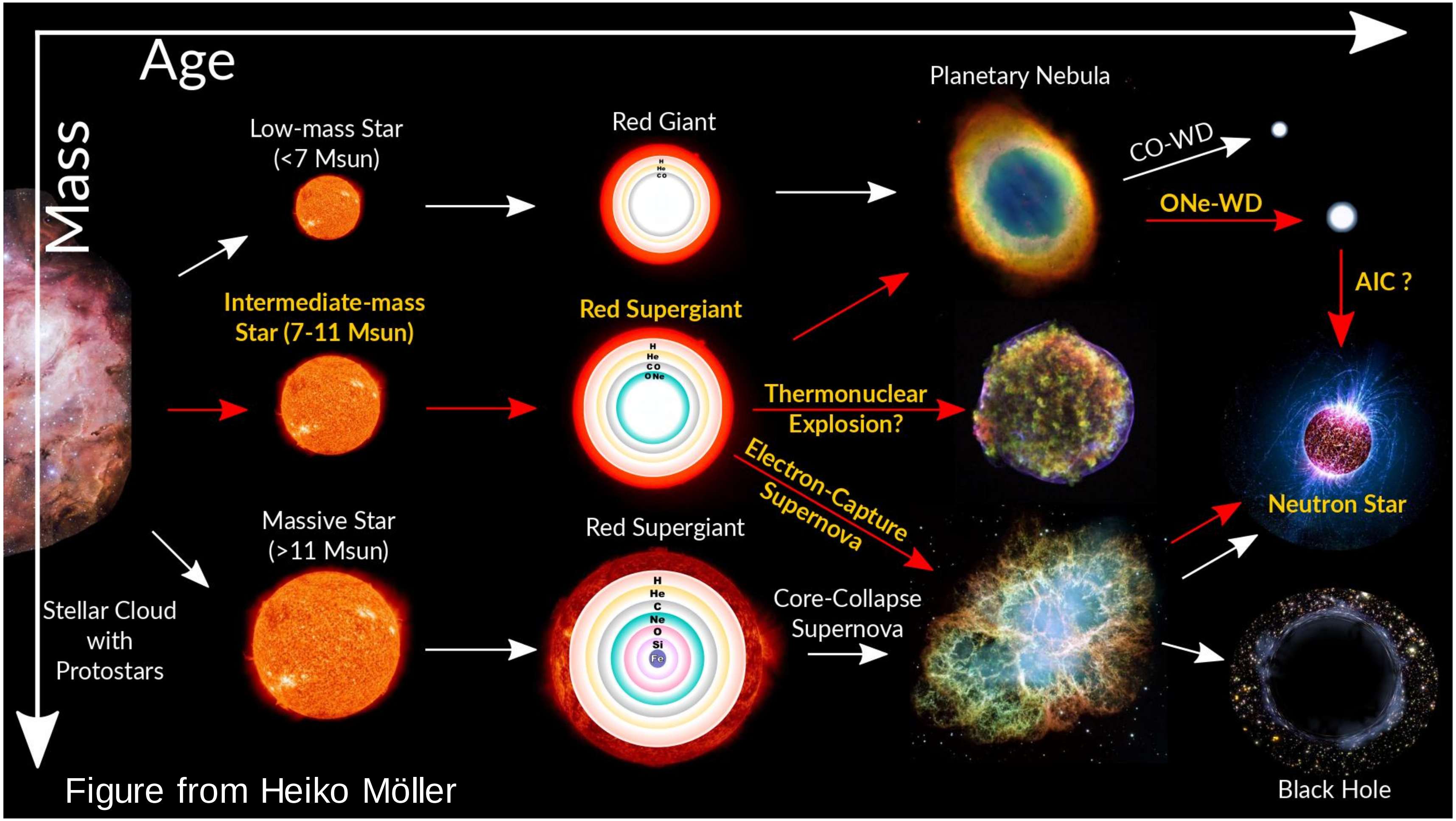
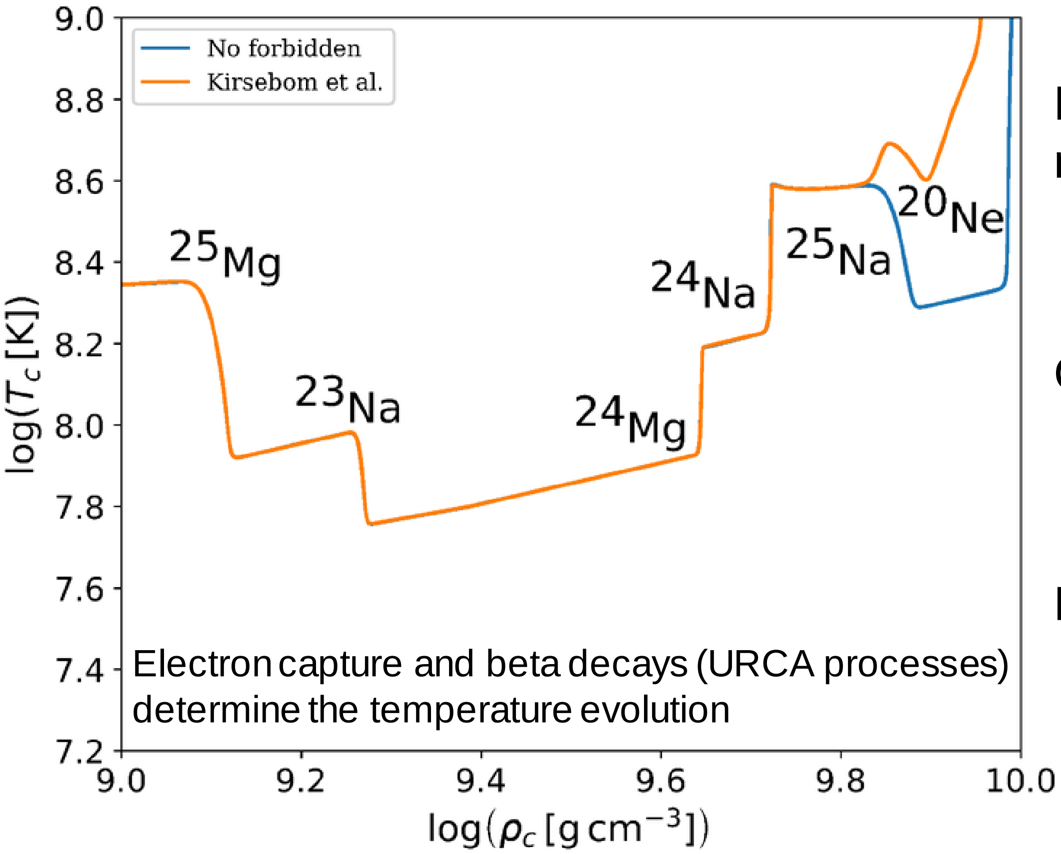


Figure from Heiko Möller

Outcome determined by the central density at which oxygen burning sets in

Central evolution ONe core

Evolution central temperature and density (Dag Fahlin Strömberg using MESA)



Largest second forbidden ever measured (JYFL)

$$\log ft = 10.51(11)$$

Compared with

$$\log ft = 13.58(3)$$

For ^{36}Cl

O. S. Kirsebom, et al, submitted to Science

Non central oxygen ignition at lower densities favors thermonuclear explosion

Open issues

- What is the impact of ^{25}Mg abundance?
- Why are the transition strengths so different for ^{20}Ne and ^{36}Cl? What about the analog E2 transitions (B02)?
- What is the role of the fourth forbidden between ^{24}Na and ^{24}Ne (B02)?
- Is Oxygen burning modified by the production of ^{20}O that allows for new reaction channels

$$^{16}\mathrm{O} + {}^{20}\mathrm{O}$$

$$^{20}\mathrm{O} + {}^{20}\mathrm{O}$$

in addition to standard channel

$$^{16}\mathrm{O} + {}^{16}\mathrm{O}$$

Kilonova: Electromagnetic transient powered by decay of r-process nuclei

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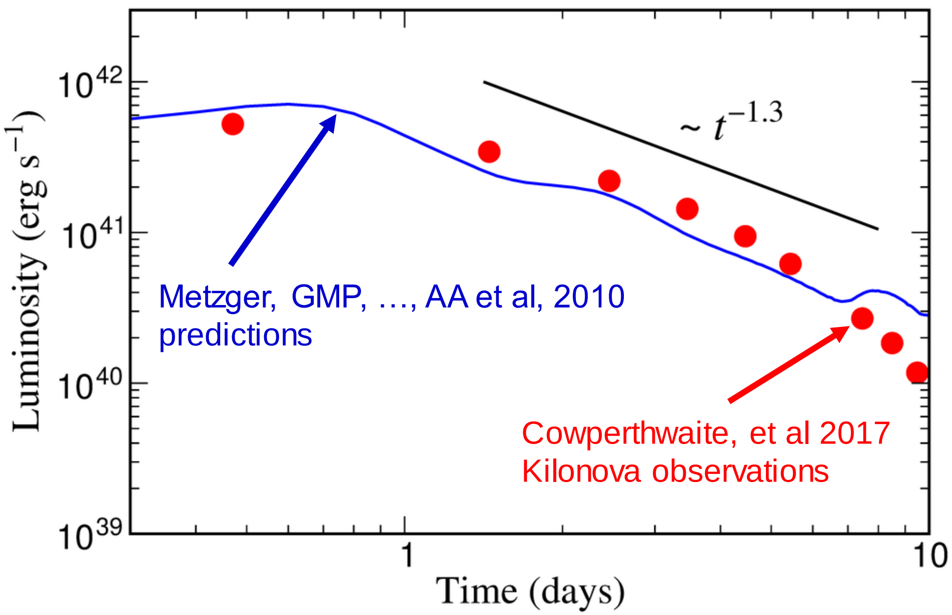

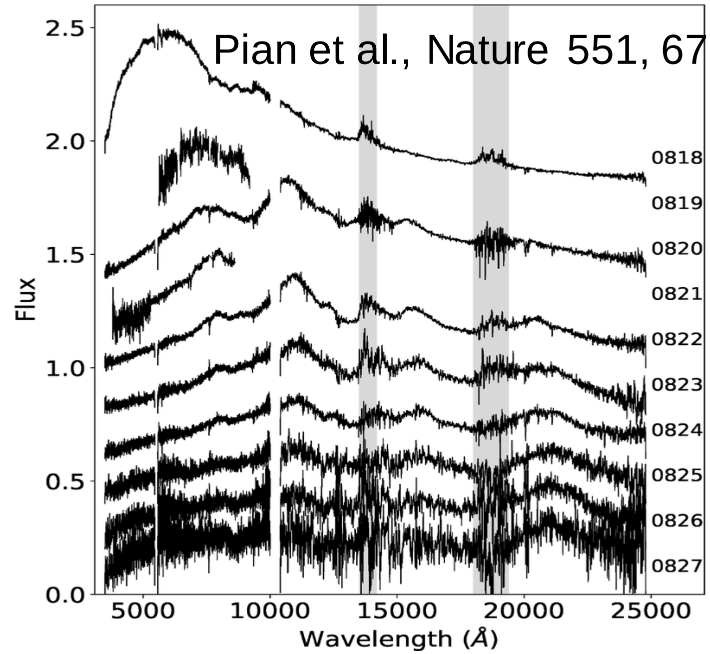

- Time evolution determined by the radioactive decay of r-process nuclei
- Two components (Kasen et al, Nature 551, 80 (2017))
  - Blue dominated by light elements (Z < 50) ($M = 0.025\, M_\odot, v = 0.3c, X_{\rm lan} = 10^{-4}$)
  - Red due to presence of Lanthanides ($M = 0.04\, M_\odot, v = 0.15c, X_{\rm lan} = 10^{-1.5}$)
- No direct evidence production of specific nuclei. No spectral features identified
- Consistent with production whole range r-process nuclei (A=69-238)

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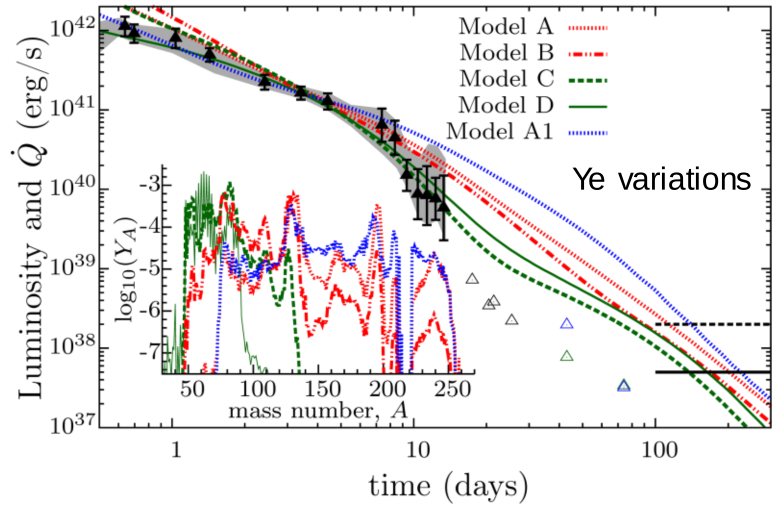
Nuclear fingerprints late-time light curve

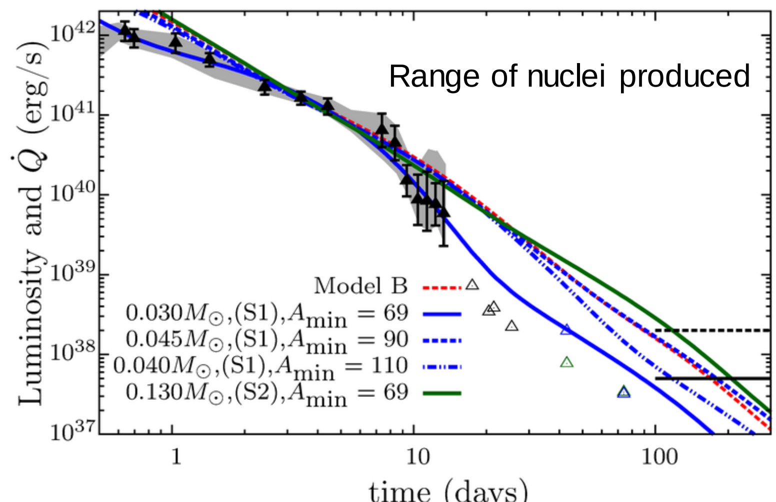
- Late-time bolometric light curve provides alternative method to constrain:
  - Ye ejected material
  - Range of nuclei produced

- Individual nuclei may dominate the light curve (α-decay of ^{223}Ra and ^{225}Ac and fission of ^{254}Cf)

- Sensitive to the yields of first peak (A~80) elements

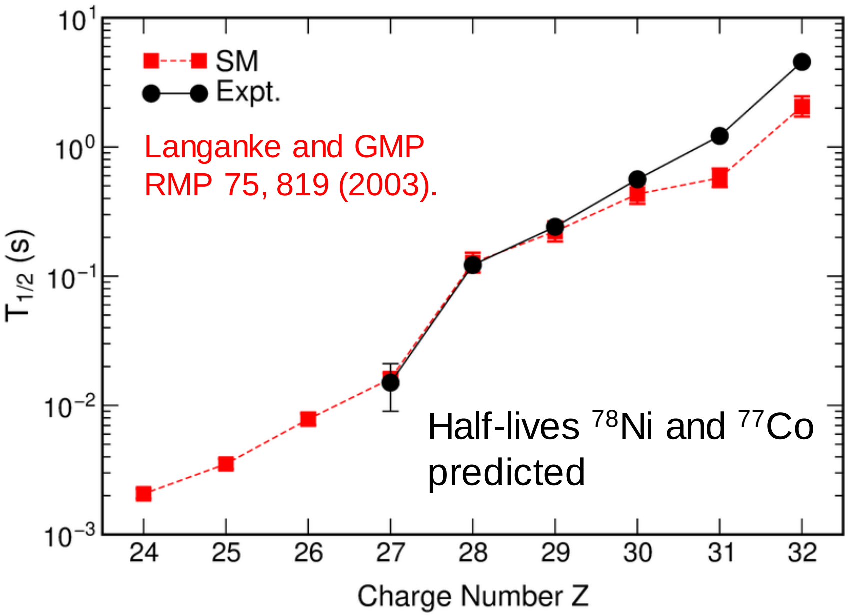
M.-R. Wu, et al, Phys. Rev. Lett. 122, 062701 (2019).



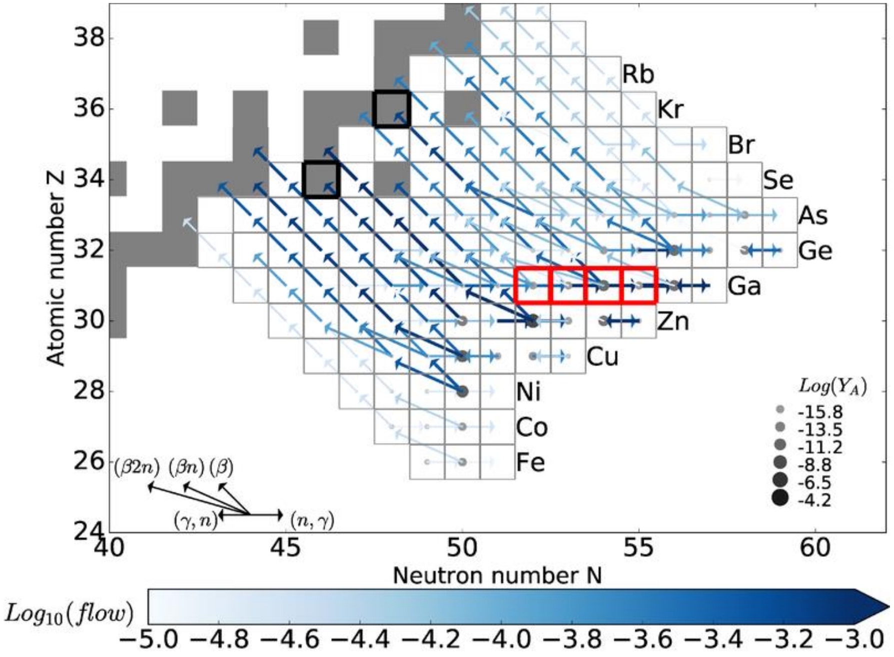


Masses and half-lives N=50 nuclei

Masses and beta-decay half-lives including beta-delayed neutron emission determine the formation of the first r-process peak



Reiter et al, arXiv:1810.11561



Extend shell-model calculations to N=50 to predict masses and beta-decay half-lives in the region

Future plans

- exploration of Gamow-Teller and forbidden transitions including many-body correlations and two-body currents (also with B02)
- comparisons against effective theories for heavy nuclei
- development of chiral-EFT-based neutrino-matter interactions consistent with the equation of state
- applications to supernova and merger simulations in B06 and B07
- understanding the impact of weak processes on the evolution of intermediate mass stars and their nucleosynthesis (with B02)
- Impact of beta-decay rates around N=50 on the production of first peak r-process elements and the associated kilonova emission.