

# Department of Energy, Office of Nuclear Physics Neutron Star Research

Office of Nuclear Physics (NP)

May 7, 2024

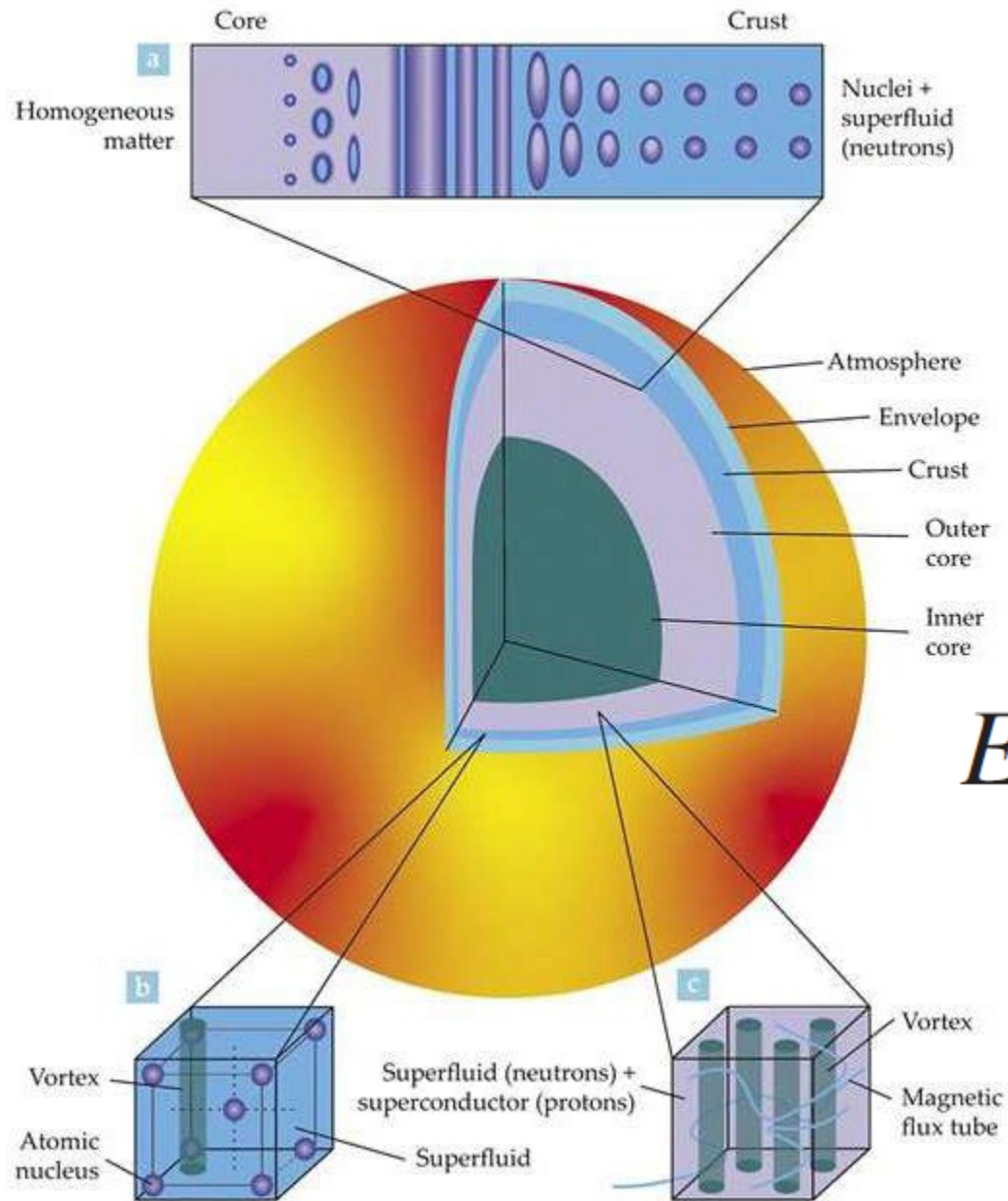
Sharon Stephenson



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

[Energy.gov/science](https://energy.gov/science)



- What is the nuclear-matter equation of state?

$$[E/A](\rho)$$

- Symmetry pressure  $L$  particularly important.

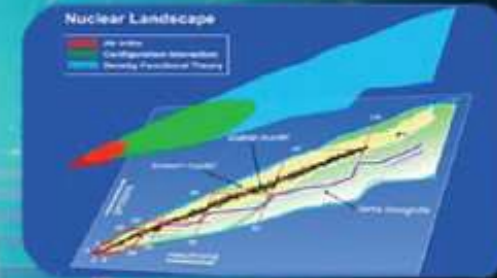
$$E_{\text{sym}}(\rho) = [E/A](\rho) - [E/N](\rho)$$

$$L = 3\rho[\partial E_{\text{sym}}(\rho)/\partial\rho]|_{\rho=\rho_0}$$

Jorge Piekarewicz, Farrukh J. Fattoyev; Neutron-rich matter in heaven and on Earth. *Physics Today* 1 July 2019; 72 (7): 30–37. <https://doi.org/10.1063/PT.3.4247>

# HEAVEN AND EARTH

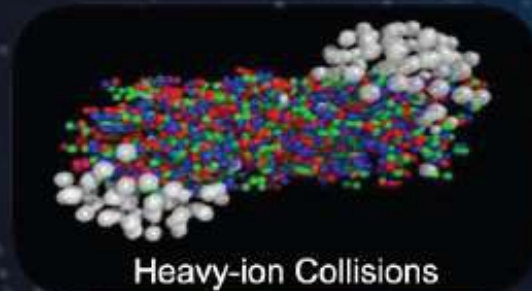
Connecting Atomic Nuclei  
to Neutron Stars –  
systems that differ in size  
by 18 orders of magnitude!



Soft X-ray Timing



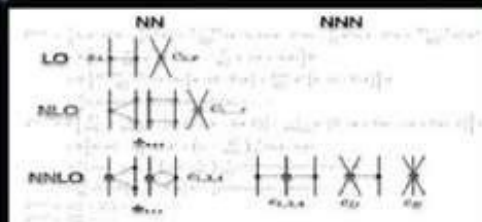
Pulsar Timing



Heavy-ion Collisions



Gravitational Waves



Chiral Effective Field Theory

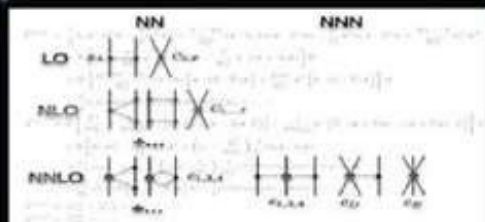
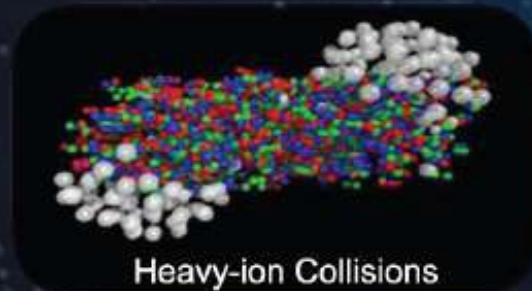
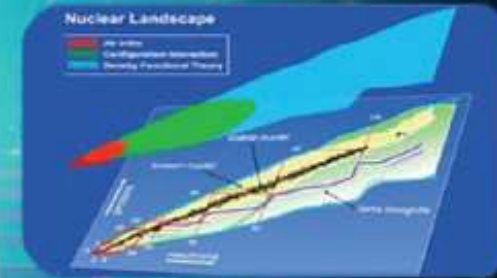


Neutron Skins

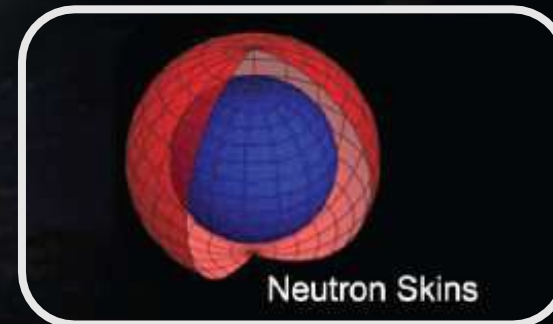


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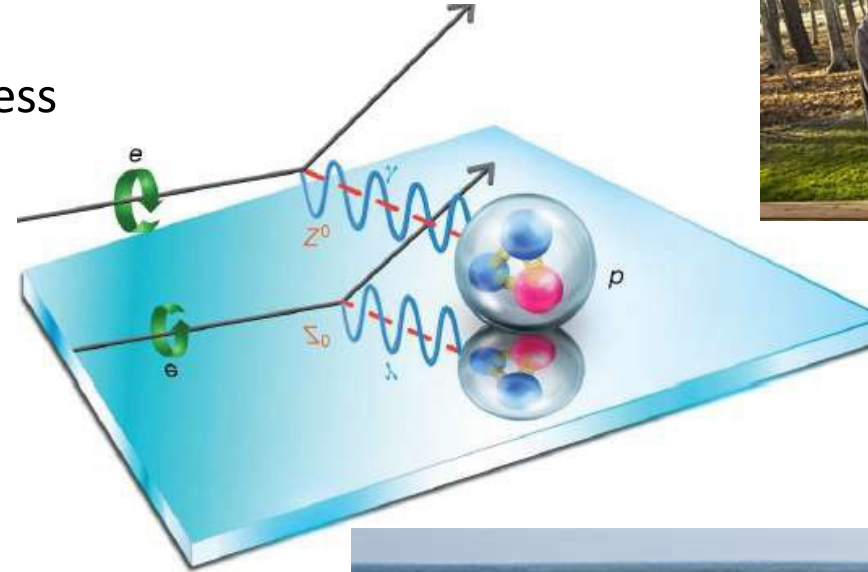
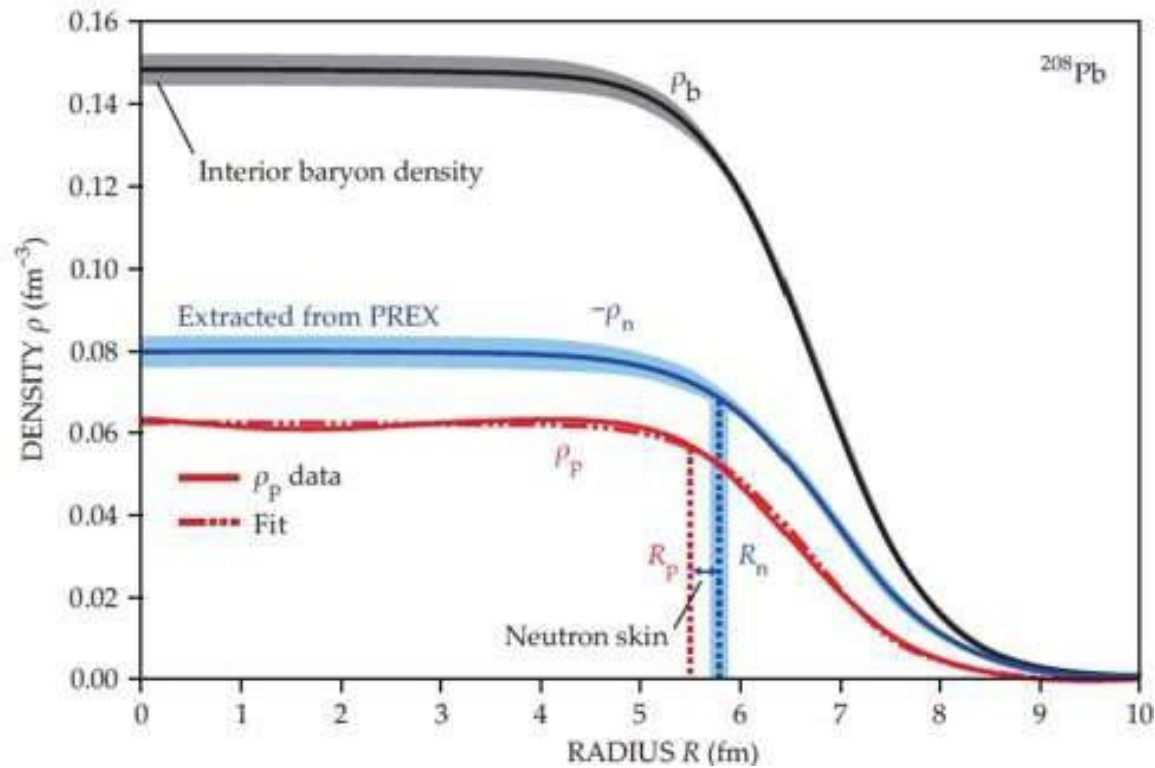


Chiral Effective Field Theory



# Neutron skins, Pb Radius Experiment PREX

- Parity-violation: flip electron spin, measure scattering rates at CEBAF
- Symmetry pressure  $L$  correlated to neutron skin thickness



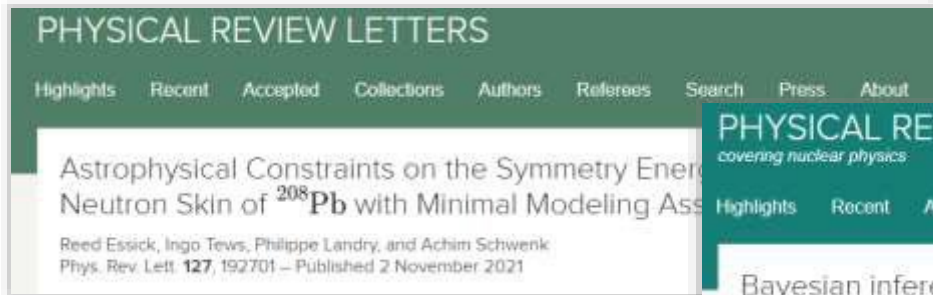
Kent Paschke



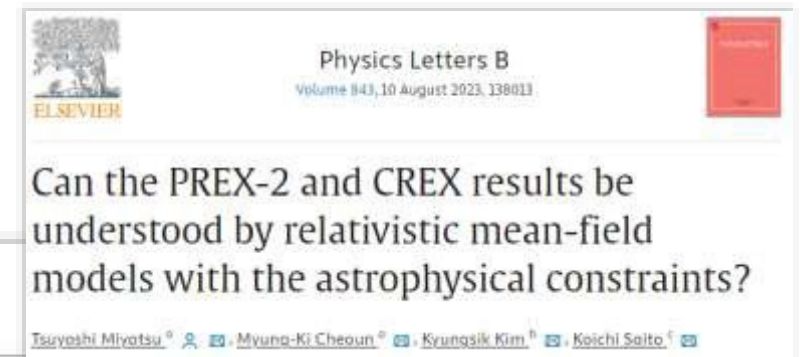
Includes researchers from **Croatia, China, Italy, Germany, Armenia, India, Canada**, and VA, LA, CT, MA, NY, PA, MS, CA, TX, ID, IN, IL, OH in the **U.S.**



# Neutron skins, PREX and beyond



Science



# Neutron skins, PREX and beyond

PHYSICAL REVIEW LETTERS

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Combined Theoretical Analysis of the Parity-Violating Asymmetry for  $^{48}\text{Ca}$  and  $^{208}\text{Pb}$

Paul-Gerhard Reinhard, Xavier Roca-Maza, and Witold Nazarewicz  
Phys. Rev. Lett. **129**, 232501 – Published 2 December 2022

PHYSICAL REVIEW LETTERS

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Astrophysical Constraints on the Symmetry Energy Neutron Skin of  $^{208}\text{Pb}$  with Minimal Modeling Assumptions

Reed Essick, Ingo Teys, Philippe Landry, and Achim Schwenk  
Phys. Rev. Lett. **127**, 192701 – Published 2 November 2021

NEWS | PHYSICS

## Neutron stars may be bigger than expected, measurement of lead nucleus suggests

Thick skin of neutrons on nucleus suggests nuclear matter is relatively stiff

27 APR 2021 • BY ADRIAN CHO

Science

particles

Article

## Constraints on Nuclear Symmetry Energy Parameters

James M. Lattimer

Particles **2023**, 6, 30–56. <https://doi.org/10.3390/particles6010003>

<https://www.mdpi.com/journal/particles>

Physics Letters B

Volume 843, 10 August 2023, 138013

## Can the PREX-2 and CREX results be understood by relativistic mean-field models with the astrophysical constraints?

Tsuyoshi Miyatsu, Myung-Ki Cheoun, Kyungsik Kim, Koichi Saito

PHYSICAL REVIEW C

covering nuclear physics

Highlights Recent Accepted Collections Authors Referees Search Press About

## Bayesian inference of the symmetry energy and the neutron skin of $^{48}\text{Ca}$ and $^{208}\text{Pb}$ from CREX and PREX-2

Zhen Zhang and Lie-Wen Chen  
Phys. Rev. C **108**, 024317 – Published 21 August 2023

PHYSICAL REVIEW LETTERS

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Editors' Suggestion

## Implications of PREX-2 on the Equation of State of Neutron-Rich Matter

Brendan T. Reed, F. J. Fattoyev, C. J. Horowitz, and J. Piekarewicz  
Phys. Rev. Lett. **126**, 172503 – Published 27 April 2021

PRL **119**, 122502 (2017)

PHYSICAL REVIEW LETTERS

week ending  
22 SEPTEMBER 2017

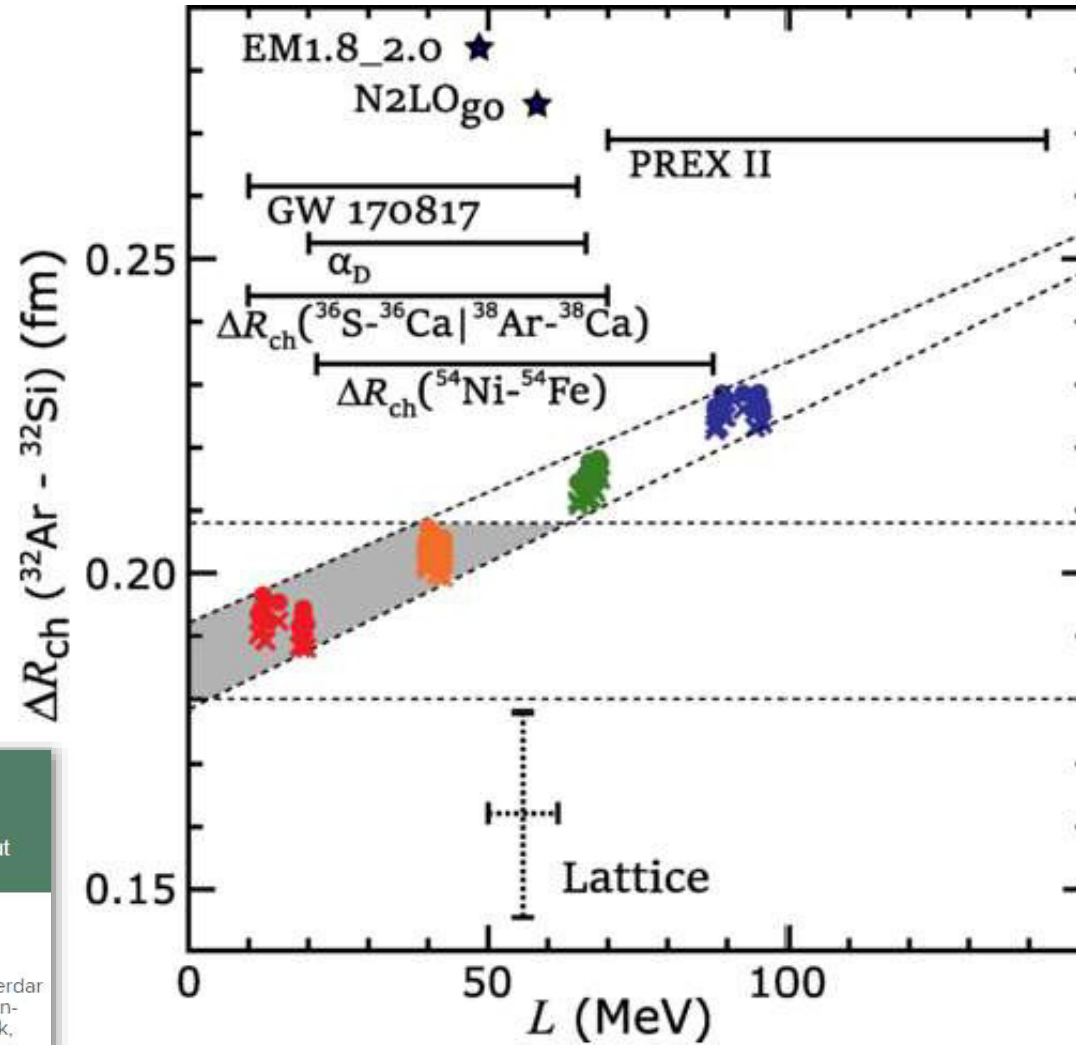
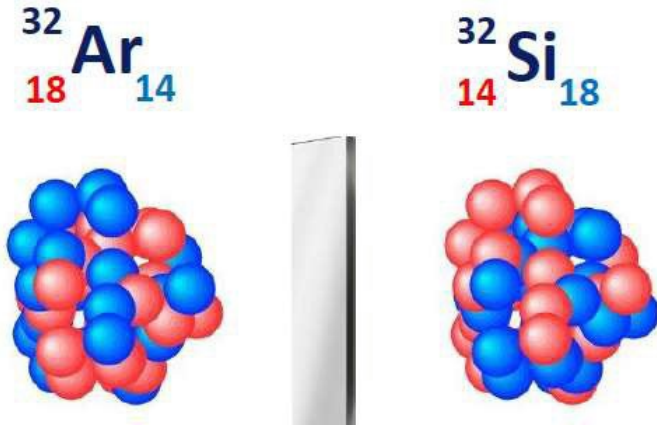
## Mirror Charge Radii and the Neutron Equation of State

B. Alex Brown

Star models from nonrelativistic and relativistic interactions

Boyang Sun, Saketh Bhattiprolu, and James M. Lattimer  
Phys. Rev. C **109**, 055801 – Published 3 May 2024

# Neutron Skins, Mirror



Kristian König

PHYSICAL REVIEW LETTERS

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Nuclear Charge Radii of Silicon Isotopes

Kristian König, Julian C. Berengut, Anastasia Borschevsky, Alex Brinson, B. Alex Brown, Adam Dockery, Serdar Elhatisari, Ephraim Eliav, Ronald F. Garcia Ruiz, Jason D. Holt, Bai-Shan Hu, Jonas Karthein, Dean Lee, Yuan-Zhuo Ma, Ulf-G. Meißner, Kei Minamisono, Alexander V. Oleynikchenko, Skyy V. Pineda, Sergey D. Prosyak, Marten L. Reitsma, Leonid V. Skripnikov, Adam Vernon, and Andréi Zaitsevskii

Phys. Rev. Lett. **132**, 162502 – Published 16 April 2024

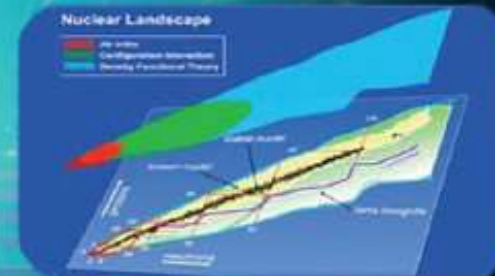
Includes researchers from **Germany, Australia, Netherlands, Turkey, Israel, Canada, Russia**, and MIT, FRIB/MSU, ORNL, in the **U.S.**

$$L = 3\rho[\partial E_{\text{sym}}(\rho)/\partial\rho]|_{\rho=\rho_0}$$



# HEAVEN AND EARTH

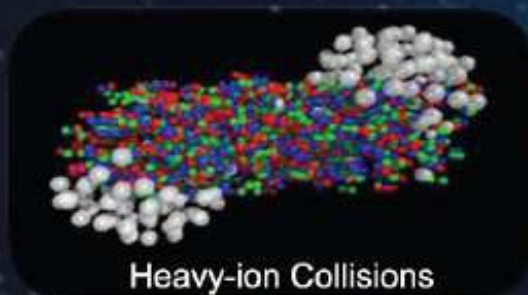
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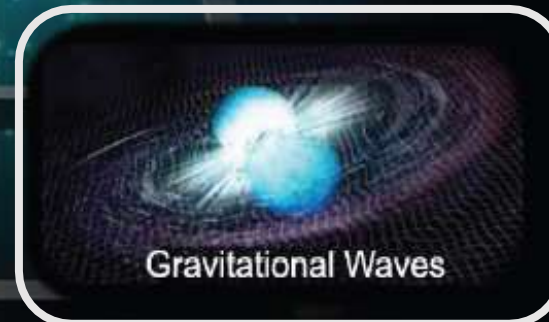
Soft X-ray Timing



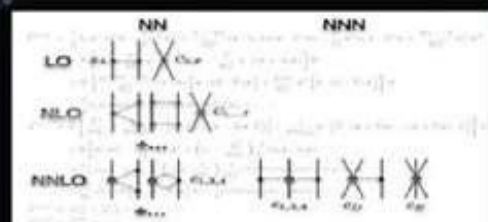
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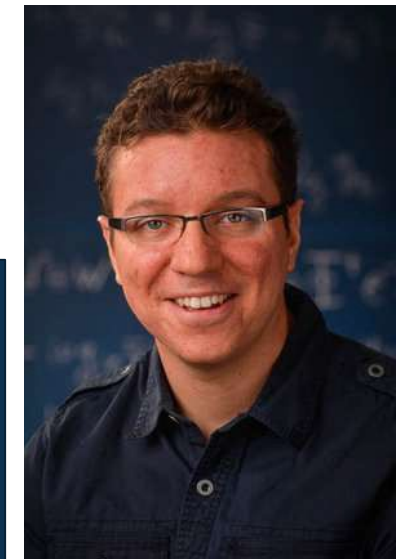
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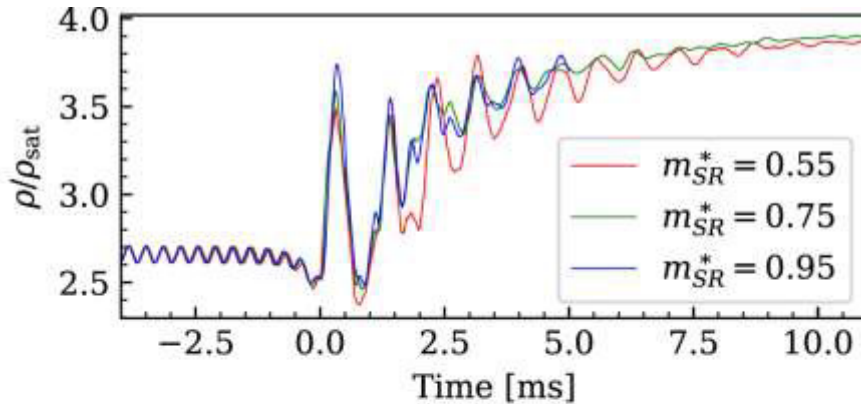
Neutron Skins



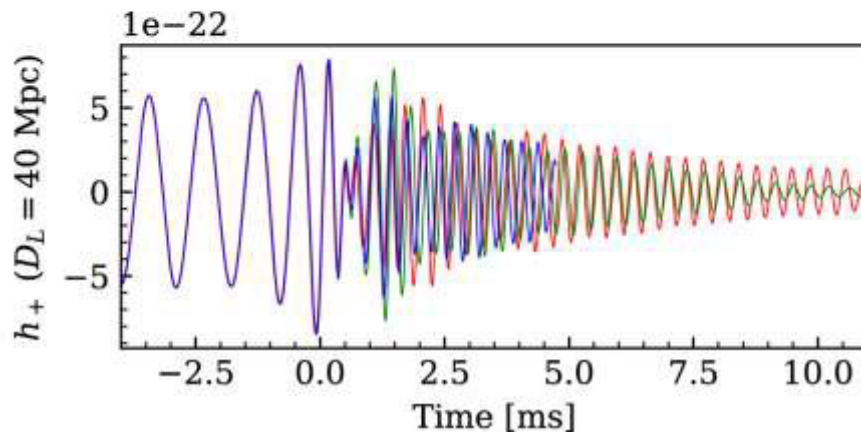
# Gravitational Waves (GW)



David Radice



- Vary effective nucleon mass  $\rightarrow$  specific heat
- Maximum rest mass density (top), GW strain predictions (bottom) for  $l=2, m=2$  mode
- Measurable effects in postmerger GW with next generation observatories



THE ASTROPHYSICAL JOURNAL LETTERS, 952:L36 (7pp), 2023 August 1  
© 2023. The Author(s). Published by the American Astronomical Society.

**OPEN ACCESS**

<https://doi.org/10.3847/2041-8213/ace5b2>



## Thermal Effects in Binary Neutron Star Mergers

Jacob Fields<sup>1,2</sup>, Aviral Prakash<sup>1,2</sup>, Matteo Breschi<sup>3,4,5</sup>, David Radice<sup>1,2,6,8</sup>, Sebastiano Bernuzzi<sup>3</sup>, and André da Silva Schneider<sup>7</sup>

Includes researchers from **Germany, Brazil, Italy** and Penn State (PA) in the **U.S.**,  
**ENAF SCIDAC (Scientific Discovery through Advanced Computing), DOE-ASCR**



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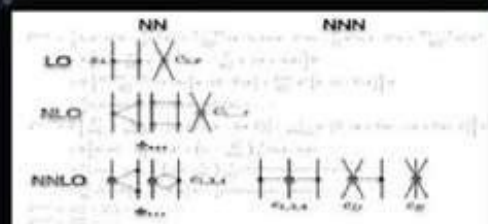
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# Nuclear Landscape

- FRIB made 5 never-before-seen isotopes of the elements thulium, ytterbium, lutetium
- N=126 – ‘one to watch’

Featured in Physics

Editors' Suggestion

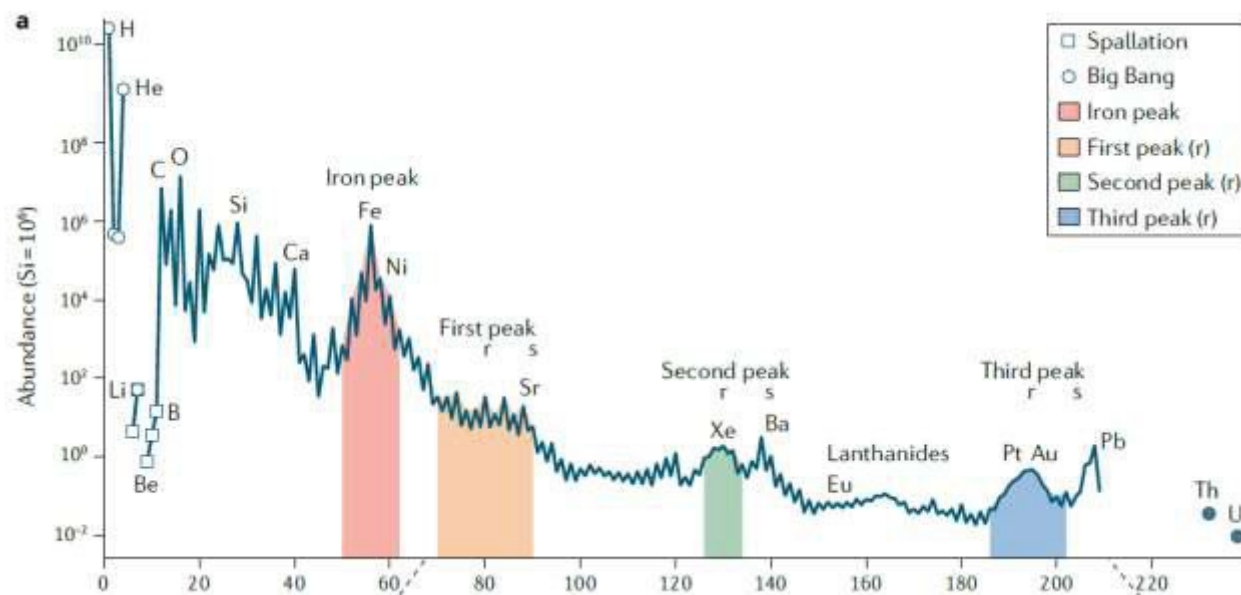
## Observation of New Isotopes in the Fragmentation of $^{198}\text{Pt}$ at FRIB

O. B. Tarasov, A. Gade, K. Fukushima, M. Hausmann, E. Kwan, M. Portillo, M. Smith, D. S. Ahn, D. Bazin, R. Chyzh, S. Giraud, K. Haak, T. Kubo, D. J. Morrissey, P. N. Ostroumov, I. Richardson, B. M. Sherrill, A. Stolz, S. Watters, D. Weisshaar, and T. Zhang  
Phys. Rev. Lett. **132**, 072501 (2024) – Published 15 February 2024

Physics: Five New Isotopes Is Just the Beginning

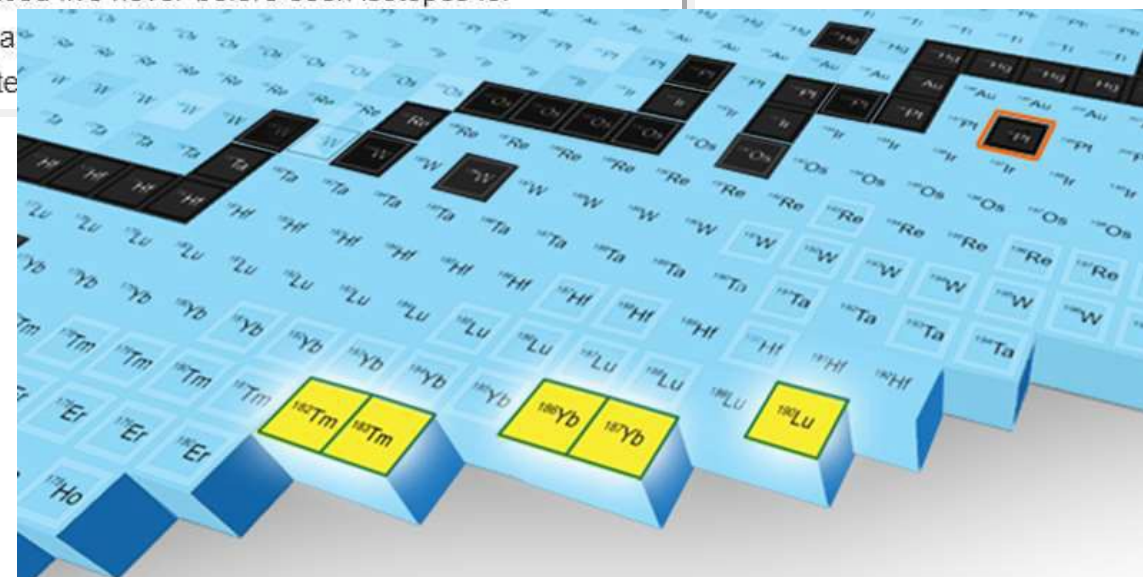


Oleg Tarasov



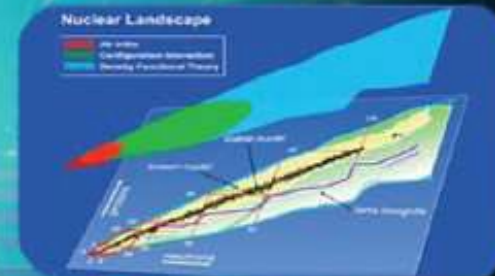
Includes researchers from RIKEN in **Japan**, IBS in **South Korea**, and MSU in the **U.S.**

In a year after its opening, the Facility for Rare Isotope Production produced five never-before-seen isotopes for...  
tion, a...  
y pote



# HEAVEN AND EARTH

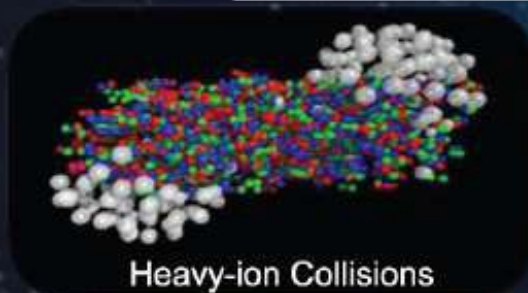
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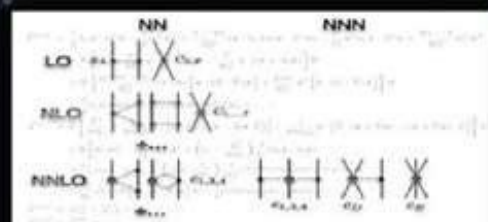
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# X-ray Binaries

## PHYSICAL REVIEW LETTERS

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First Direct Measurement Constraining the  $^{34}\text{Ar}(\alpha, p)^{37}\text{K}$  Reaction Cross Section for Mixed Hydrogen and Helium Burning in Accreting Neutron Stars

J. Browne *et al.* (JENSA Collaboration)  
Phys. Rev. Lett. **130**, 212701 – Published 22 May 2023

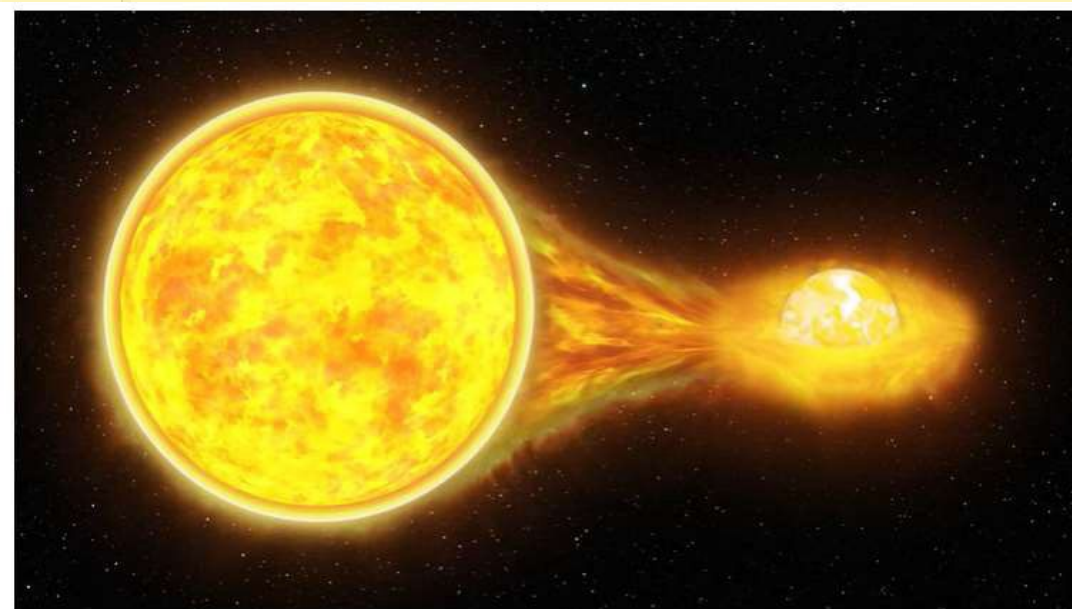
PHYS  ORG

Element creation in the lab deepens understanding of surface explosions on neutron stars

Includes researchers from **South Korea, Germany**, and ORNL, LSU, Mines, FRIB/MSU, UTK, Rutgers in the **U.S.**



Kelly Chipps





# Summary

- Highlighted some lab-based experiments and theoretical work relevant to neutron star properties.
- Larger picture – neutrinos, isomers, advancements in theory, kilonova, scope at ATLAS, scope at RAISOR, exascale computing, AI/ML, nuclear data.
- NSF and NASA contributions to the ‘ladder’ are greatly valued and highly leveraged.

