CYCLOTRON INSTITUTE
TEXAS A&M UNIVERSITY

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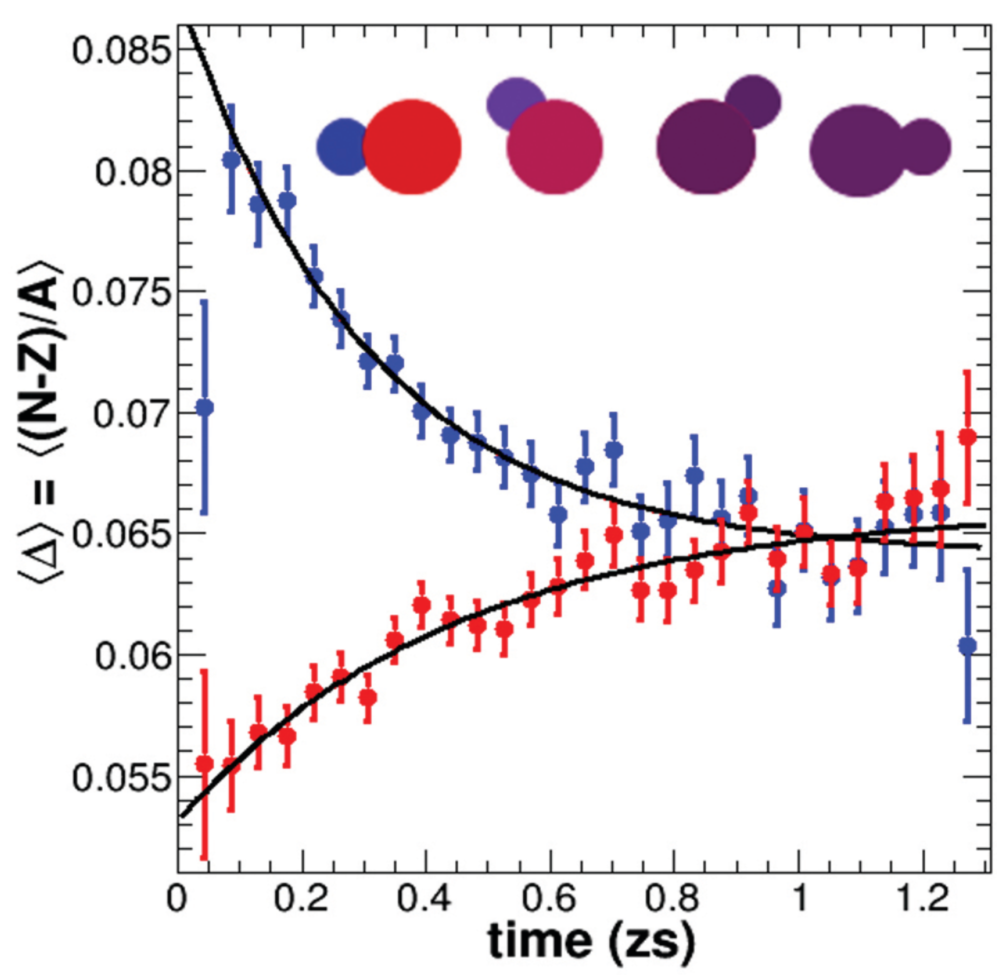
EQUILIBRATION CHRONOMETRY

Measuring the migration of neutrons within deformed nuclei with extreme time precision

THE SCIENCE
The nuclear equation of state describes how hard it is to squeeze a nucleus, how hot it gets when you squeeze it, and how that changes when more neutrons are added to the nucleus. The role of excess neutrons is important but not well understood. Researchers at the Texas A&M University Cyclotron Institute have used a new technique, equilibration chronometry, to monitor the transfer of excess neutrons as a functions of time. The time resolution of about 10-to-22 seconds is sufficient to see that the movement of neutrons toward an equilibrium configuration is exponential, indicating the equilibration follows first order kinetics.

THE IMPACT
The nuclear equation of state is a stunning example of the connections that exist between vastly different aspects of science, reaching from the behavior of the nuclei of atoms to astrophysical extremes. By measuring the timescale and kinetics of how neutrons move toward equilibration, the underlying equation of state can be constrained. A more accurate equation of state then leads to improved predictive powers regarding the features of heavy-ion collisions, the structure and composition of neutron stars, and the formation of the chemical elements in explosive nucleosynthesis.

SUMMARY
By colliding ^{70}Zn projectiles moving at one quarter the speed of light with stationary ^{70}Zn nuclei, the researchers created extremely deformed nuclei. Specifically, these elongated shapes had a smaller end that is neutron-rich and a larger end that is relatively neutron-poor. These deformed nuclei were spinning as they broke into two fragments, and the decay occurred before one full rotation was reached. By measuring the rotation rate, the final orientation of the two daughter fragments provide a measure of the time scale of the decay, which is less than 5×10^{-22} seconds on average. Before these two fragments part ways, the excess neutrons from the neutron-rich end migrate toward the relatively neutron-poor end. This equilibration ceases when the deformed nucleus breaks in two. The neutron excesses of the two fragments are initially far from each other, and approach each other exponentially as a function of time.



Equilibration chronometry allows the extremely rapid transfer excess neutrons within a deformed nuclear system to be observed as a function of time.

Alan McIntosh

Andrea Jedele

PUBLICATIONS
A. Jedele, A. B. McIntosh, K. Hagel, M. Huang, L. Heilborn, Z. Kohley, L.W. May, E. McCleskey, M. Youngs, A. Zarrella, and S. J. Yennello, "Characterizing Neutron-Proton Equilibration in Nuclear Reactions with Subzeptosecond Resolution," Phys. Rev. Lett. 118, 062501 (2017).

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ABOUT THE CYCLOTRON INSTITUTE: *Dedicated in 1967, the Cyclotron Institute serves as the core of Texas A&M University's accelerator-based nuclear science and technology program. Affiliated faculty members from the Department of Chemistry and Department of Physics and Astronomy conduct nuclear physics- and chemistry-based research and radiation testing within a broad-based, globally recognized interdisciplinary platform supported by the United States Department of Energy (DOE) in conjunction with the State of Texas and the Welch Foundation. The facility is one of five DOE-designated Centers of Excellence and is home to one of only five K500 or larger superconducting cyclotrons worldwide.*