Scientists directly measure a key reaction in neutron star binaries

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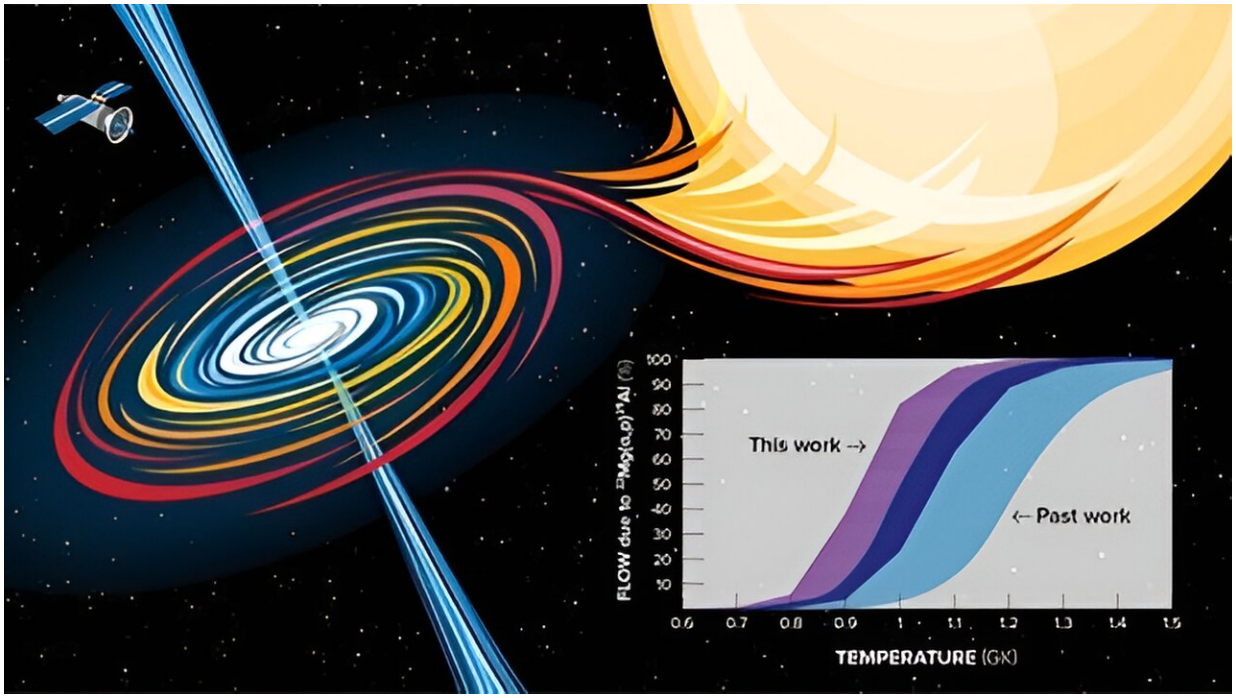

A neutron star accreting material from a companion star, producing periodic X-ray bursts. Inset shows how the new data affect the temperature dependence of the synthesis flow of chemical elements through the ^{22}Mg(α,p)^{25}Al reaction. Credit: Argonne National Laboratory.

An X-ray burst (XRB) is a violent explosion that occurs on the surface of a neutron star as it absorbs material from a companion star. During this absorption, increasing temperatures and densities on the surface of the neutron star ignite a cascade of thermonuclear reactions.

These reactions create atoms of heavy chemical elements. A study, published in *Physical Review Letters*, presents an investigation of one of these reactions, $^{22}Mg(\alpha,p)^{25}Al$ (magnesium-22 and helium-4, producing a proton and aluminum-25). The rate of this reaction plays a major role in informing models of XRBs and determining the reaction mechanisms that power these explosions. The researchers found that the reaction rate is four times higher than the previous direct measurement.

XRBs are driven by a sequence of reactions involving unstable nuclei that rapidly capture protons before the nuclei have a chance to decay. During this sequence, the rate of particular proton capture reactions decreases at multiple "waiting point" nuclei (such as magnesium-22), causing the nuclear flow to slow down.

Research has found that the capture of alpha particles (helium-4) by these nuclei instead of protons could bypass these waiting points and continue the synthesis of heavier elements. Precisely determining the rates of possible reactions at the waiting points—including the $^{22}Mg(\alpha,p)^{25}Al$ reaction at the magnesium-22 waiting point—can help scientists improve their understanding of XRBs.

The $^{22}Mg(\alpha,p)^{25}Al$ reaction involves unstable nuclei with lifetimes too short for the nuclei to be made into targets. To measure this reaction, scientists performed the measurement in inverse kinematics using the Argonne Tandem Linac Accelerator System (ATLAS), a Department of Energy user facility at Argonne National Laboratory.

The researchers developed an in-flight radioactive beam with the ATLAS in-flight system. The beam was delivered to the MUlti-Sampling Ionization Chamber (MUSIC) detector filled with pure helium gas, recreating conditions relevant for XRBs.

The experiment yielded a new direct measurement of the angle and energy-integrated cross-section of the $^{22}\mathrm{Mg}(\alpha,p)^{25}\mathrm{Al}$ reaction. The cross-section is a measure of the probability that the reaction will occur.

The experiment found that this probability is four times higher than the previous direct measurement. This higher rate indicates a higher likelihood that the $^{22}\mathrm{Mg}$ waiting point is bypassed by the $^{22}\mathrm{Mg}(\alpha,p)^{25}\mathrm{Al}$ reaction. In addition, the scientists found that the reaction begins to occur at lower temperatures than previously thought.

The new result provides insight into the underlying physics of the nucleosynthesis reaction flow through the $^{22}\mathrm{Mg}$ waiting point in XRBs.

More information: H. Jayatissa et al, Study of the Mg22 Waiting Point Relevant for X-Ray Burst Nucleosynthesis via the Mg22(α,p)Al25 Reaction, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.131.112701

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