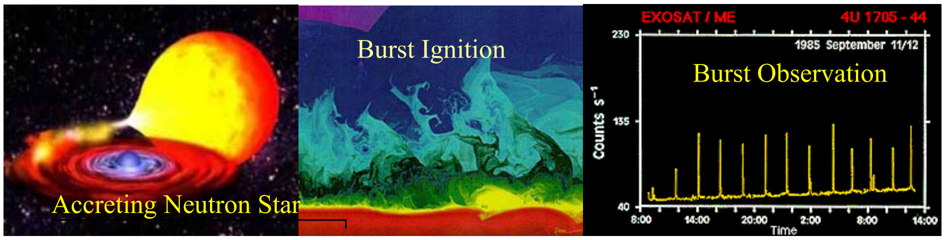
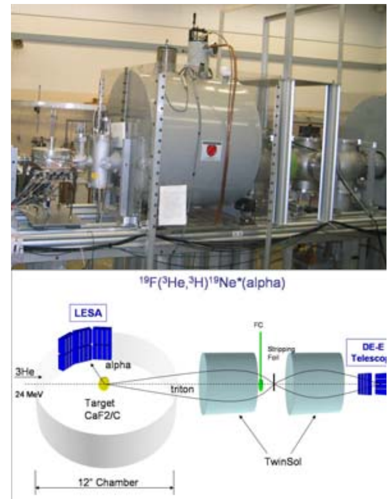
The Nuclear Trigger of Type I X-ray Bursts



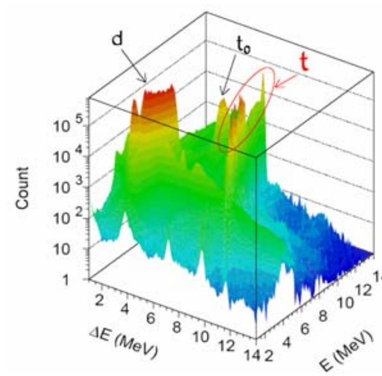
X-ray bursts belong to the most fascinating of astrophysical phenomena. They are explained as thermonuclear explosions in the outer atmosphere of accreting neutron stars. The accreted hydrogen and helium rich material burns through steady fusion processes heating the neutron star atmosphere towards the ignition point. The thermonuclear explosion is triggered by the $^{15}O(\alpha,\gamma)^{19}Ne$ reaction which is the gateway to rapid conversion of the initial carbon, oxygen material to heavier elements in the nickel to cadmium range. This releases nuclear energy of up to 10^{40} ergs per burst. X-ray bursts are now frequently observed with modern space based telescopes and show a recurrence frequency ranging from hours to days. Change in accretion conditions lead to interruption of the recurrent burst pattern. The reaction rate of $^{15}O(\alpha,\gamma)^{19}Ne$ determines the exact ignition conditions and provides experiment based limits for the accretion rate.

Twenty years ago it was predicted that the reaction rate is dominated by a single resonance with 4.03 MeV excitation energy in ^{19}Ne [1]. Numerous research groups have tried to measure the resonance and its strength and determine the trigger temperature for X-ray bursts. A direct measurement of the resonance would require high intensity radioactive ^{15}O beams which have not been achieved yet at present radioactive beam facilities. Indirect studies require highly sensitive measurements of the very weak α-decay branch of the resonance level. Despite considerable effort over the years, our present knowledge is limited to an estimate of the upper limits of the strength.

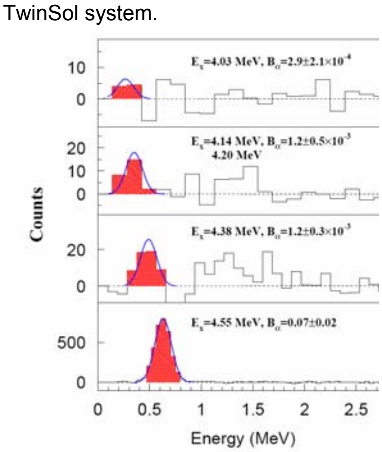
We have performed the first successful measurement of the α-decay of the 4.03 MeV state using the Notre Dame TwinSol system. The α-branching ratio was uniquely determined for all of the α-unbound states in ^{19}Ne by coincidence measurements between the tritons from the $^{19}F(^3He,t)$ reaction populating the levels and the subsequent α-decay products. Based on this result, coupled with the first successful lifetime measurement for the 4.03 MeV level at Notre Dame [2], the reaction rate is determined with much improved



Set-up of the experiment for measuring the $^{19}F(^3He,t)^{19}Ne^*(\alpha)^{15}O$ reaction at the Notre Dame TwinSol system.

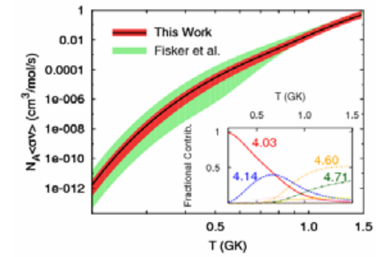


Particle identification spectrum as measured at the focal point of the TwinSol system.

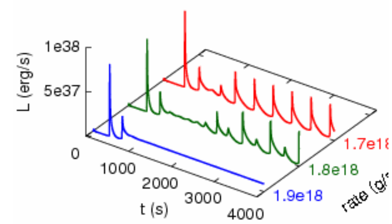


Coincident α-decay spectra for each of the near threshold resonance levels in ^{19}Ne as measured with the LESA detection system. Higher energy α particles are from the decay of higher energy states.

accuracy. This result allows us to derive many quantitative predictions about the X-ray burst behavior and characteristics. Most important, it allows us to determine the ignition point of the thermonuclear runaway. It provides also for the first time stringent experimental limitations for the neutron star accretion rate leading to the observed recurrent type-I burst patterns. Our simulations of the burst behavior for varying accretion conditions suggest that the transition point between thermonuclear runaway and steady state burning is at $1.9 \cdot 10^{18}$ g/s. This is an excellent example for nuclear laboratory data providing stringent limits for the model interpretation of astrophysical observations; in this case the identification of the boundaries conditions for stellar thermonuclear explosion at the extreme environmental condition prevailing on the surface of a neutron star.



The reaction rate for $^{15}O(\alpha,\gamma)^{19}Ne$ as a function of temperature. The red shaded area marks the present uncertainty range and the green shaded area the previous one.



Type I X-ray burst pattern as calculated for different accretion rate in the range of the present uncertainties for the $^{15}O(\alpha,\gamma)^{19}Ne$ reaction rate.

Publications:

[1] K. Langanke, M. Wiescher, W.A. Fowler, J. Görres, Astrophys. J. 301, 629(L) (1986)

[2] W.P. Tan, J. Görres, J. Daly, M. Couder, A. Couture, H. Y. Lee, E. Stech, E. Strandberg, C. Ugalde, M. Wiescher, Phys. Rev. C 72, 041302(R) (2005)

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