Near and sub-barrier fusion of neutron-rich light nuclei

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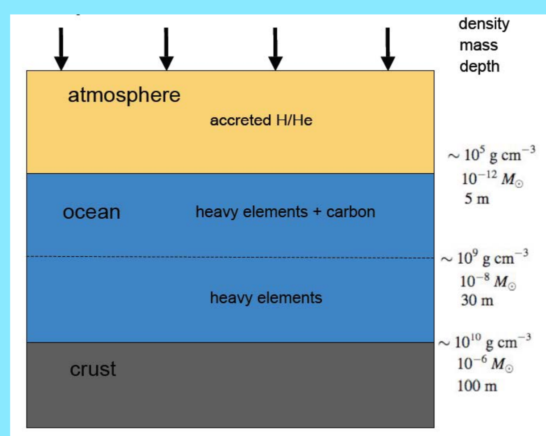
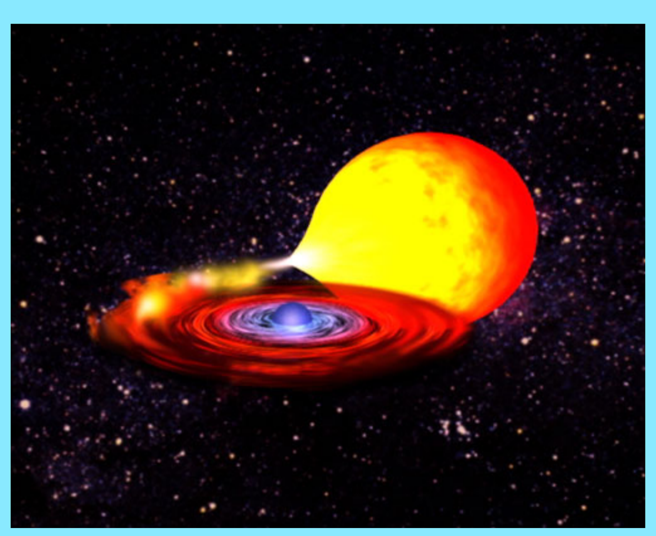
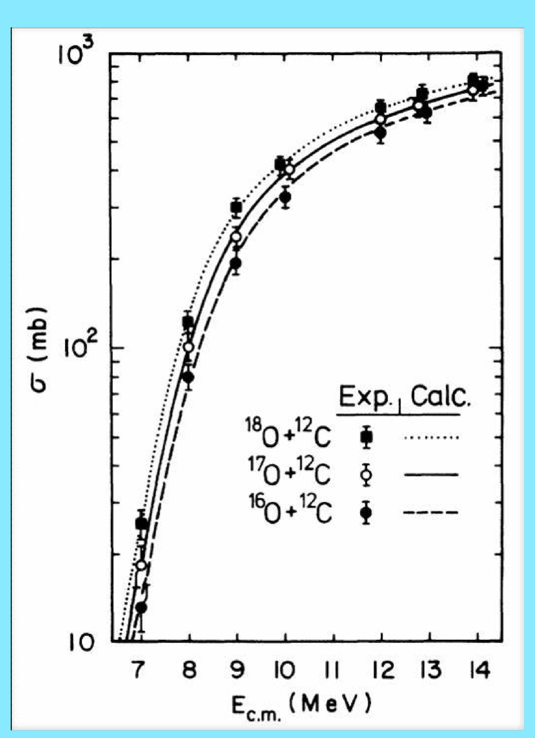
Motivation

Neutron star crusts present a unique environment for nuclear reactions to occur. The rising electron Fermi energy enhances the rate of electron capture reactions at the density of the outer crust, leading to the production of neutron-rich isotopes.



Accreting neutron stars have been identified as the origin of energetic X-ray superbursts. Since the temperature of a neutron star is ~ 1 GK, the fusion of the two nuclei is strongly suppressed by the Coulomb barrier. It has been proposed that enhanced fusion of neutron-rich nuclei in the outer crust provides the necessary heat source to ignite the fusion of two ^{12}C nuclei and fuel the subsequent X-ray superbursts.





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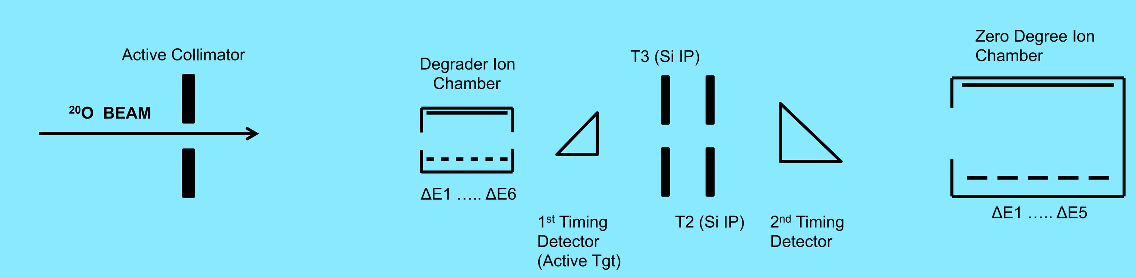
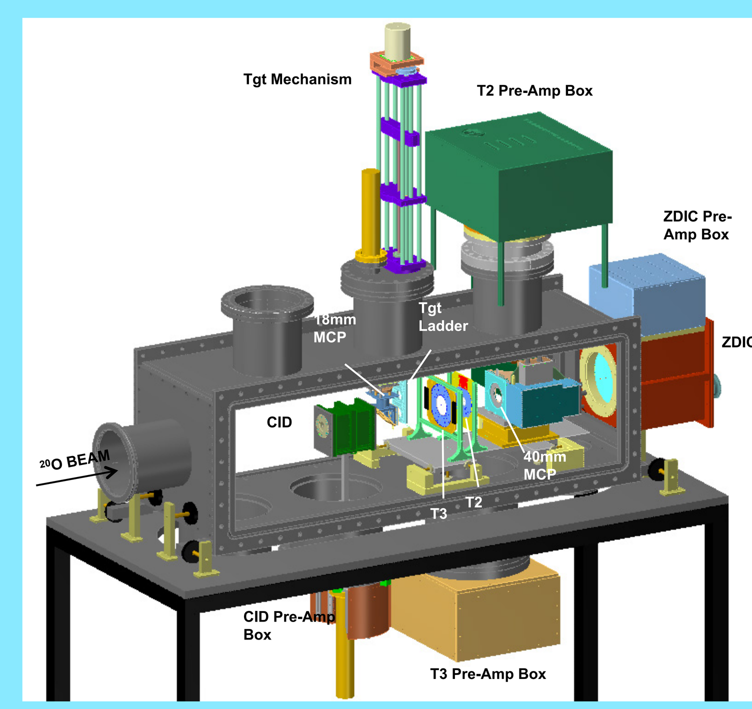
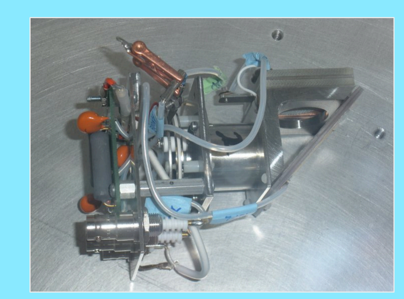
Calculations indicate that fusion of two ^{24}O nuclei is a potential heat source. As this reaction is presently experimentally inaccessible, we have chosen to study fusion of neutron-rich oxygen with ^{12}C. The fusion cross-section in previously measured fusion excitation functions for ^{16,17,18}O + ^{12}C are enhanced due to the increased size of the incident oxygen. The extent to which the fusion cross-section increases with increasing neutron number is presently an open question.

Expt. E575S conducted at GANIL-SPIRAL July 2010

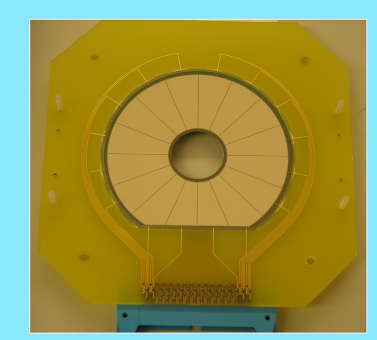
Experimental Design





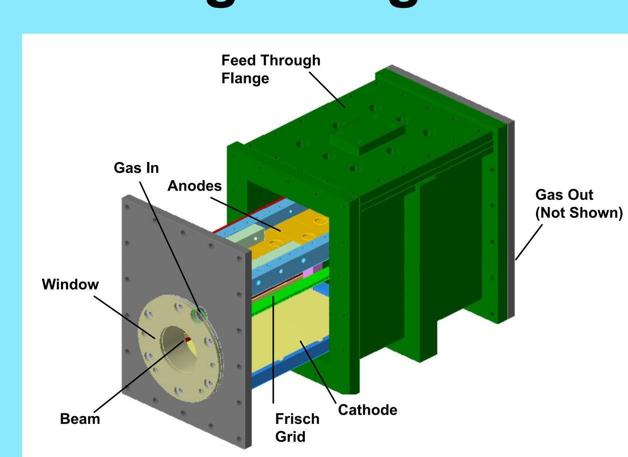


Micro-channel Plate Detector

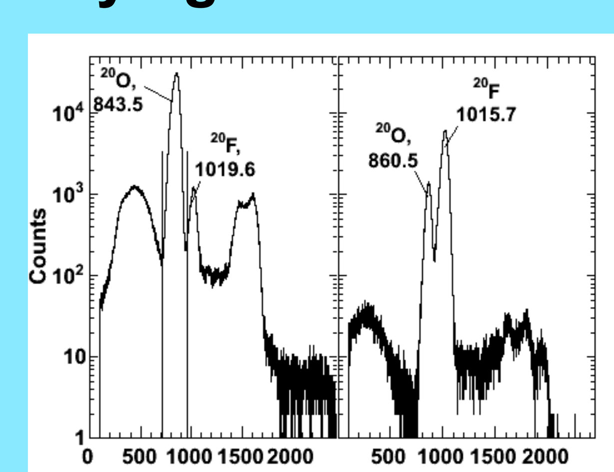


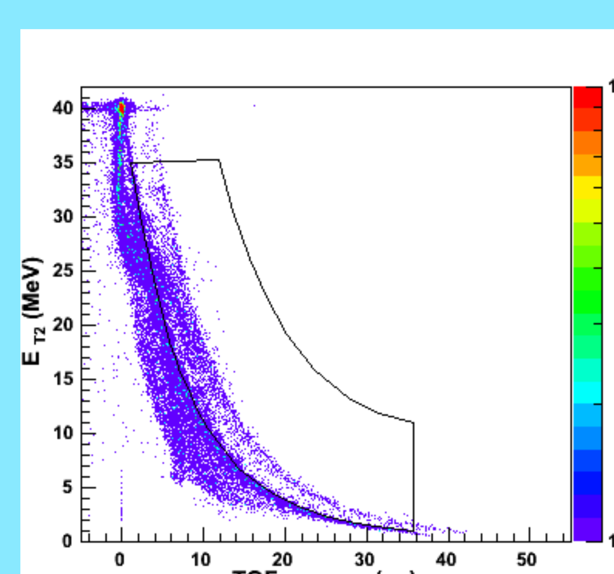
T2 (16 Pies 48 Rings)

Degrading and Identifying the Beam



Degrader Ion Chamber (CID)



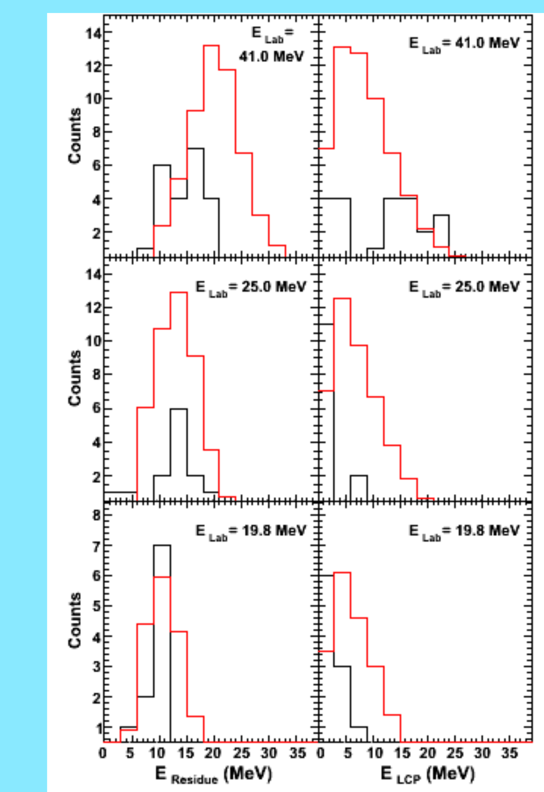


Energy TOF spectrum for particles detected in T2. The gate indicates the region explored for coincidences between the evaporation residues and the LCPs.

- Beam: ^{20}O @ 1-2x10^4 pps
- Target: 100 μg*cm^{-2} Carbon
- E_B: 3 MeV/A $\xrightarrow{CID}$ 1-2 MeV/A
- Energy Resolution: 260 keV @ 41 MeV
- Average energy and dispersion of the degraded beam measured by a surface barrier detector
- Time Resolution: <600 ps

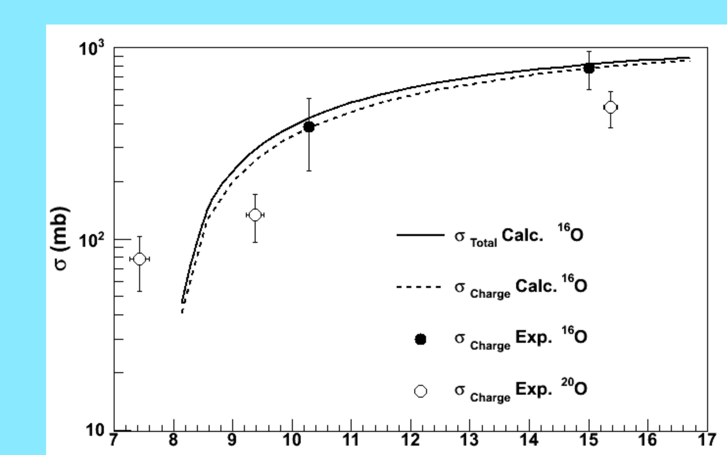
Results

By looking for light charged particles (LCPs) in the S1 silicon (11.31°≤ θ_{lab}≤ 21.80°) and fusion residues in the S2 (3.54°≤ θ_{lab}≤ 10.85°) the cross-section for these charged particle de-excitation channels can be experimentally determined. The efficiency for the detection of the charged particle channels as a function of beam energy was determined by using the fusion evaporation model evapOR*, filtered by the experimental acceptance.

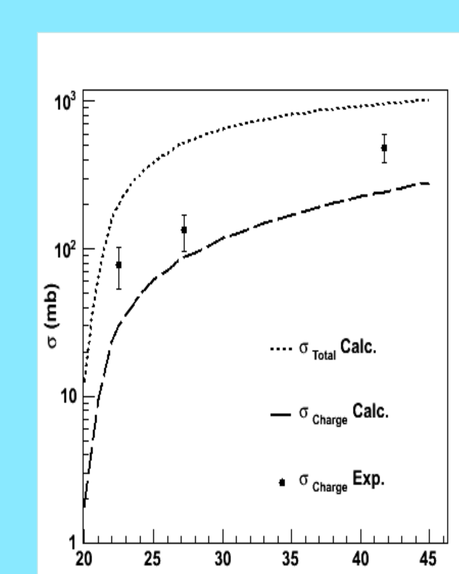


The theoretical predictions from evapOR match the deposited energy in the silicon detectors for residues and the light charged particles.

Fusion followed by charged particle decay in ^{16}O + ^{12}C using the same experimental setup was measured at Western Michigan University Tandem Accelerator in March 2011. Comparison of the experimental data with the predictions of evapOR shows good agreement.



The statistical model prediction matches the measured fusion cross-section of ^{16}O + ^{12}C and the charged particle de-excitation of ^{28}Si*.



The cross-section measured for the charged particle channels of ^{20}O + ^{12}C was found to be roughly two times the predicted cross-section from evapOR. This result means either the total fusion cross-section is larger than that predicted by the model, or the model under-predicts charged particle emission relative to neutrons.

*evapOR, Oak Ridge National Laboratory