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Nuclear Astrophysics

The field of Nuclear Astrophysics is concerned with the application of nuclear physics to astrophysics. Nuclear processes are responsible for producing the elements in the Universe as well as generating the energy which allows stars to shine.

Our research is primarily focused on the determination of the rates of nuclear reactions in quiescent and explosive stellar environments.

Many experiments are performed with the local accelerator. Other measurements, particularly studies of reaction rates involving radioactive nuclear species, are performed elsewhere – for example radioactive beam experiments at Oak Ridge National Laboratory.

CNO Breakout

Nuclear reactions which "break out"from the standard CNO cycle, typically involving proton-rich unstable nuclei.

- (^{3}He, n) Reactions. These reactions provide spectroscopic information on proton-rich nuclei. Measurements of (^{3}He, n) on ^{17}O, ^{24}Mg, and ^{28}Si targets are planned for the future.

- Radioactive Flourine Beam Measurements. ^{17,18}F beams with intensities of $\approx 10^6$ ions/sec on target are available at ORNL. These intensities are sufficient to measure proton-transfer reactions such as ^{14}N(^{17}F,^{18} Ne) (analysis underway). In the future we hope to measure proton-transfer reactions with ^{18}F as well as the ^{17}F$(p,\gamma)^{18}$Ne reaction directly (if sufficient beam is available).

Other Projects

- Level Densities for Unstable Nuclei – Determine the nuclear level densities in nuclei near the r- or rp-process path by measuring the evaporation spectra from reactions induced by radioactive ion beams at Oak Ridge National Lab.

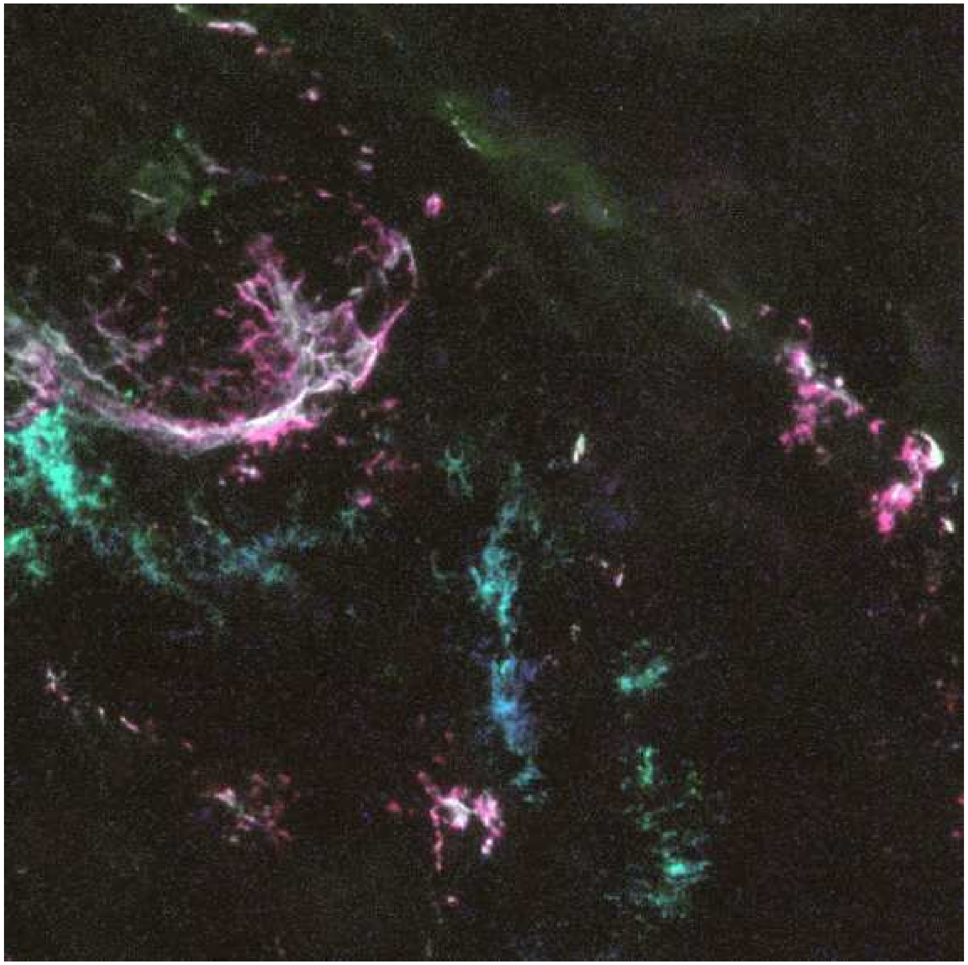
- (α, n) Reactions – Measure the differential cross sections for the $^{9}\mathrm{Be}(\alpha, n)^{12}\mathrm{C}$ and $^{11}\mathrm{B}(\alpha, n)^{14}\mathrm{N}$ reactions. The former reaction is interesting because it is a key link in the "neutron-catalyzed triple α process" $3\alpha + n \rightarrow {}^{12}\mathrm{C} + n$ which is thought to occur immediately following type-II supernova explosions. Both reactions also have implications for nuclear structure and applied nuclear physics.

Supernova Remnant N132D

Hubble Space Telescope image of the 3,000-year-old supernova remnant N132D in the Large Magellanic Cloud. The precursor star to this remnant is estimated to have been 25 times more massive than our Sun. Supernova events of this type produced many of the heavier elements in our solar system, including carbon, oxygen, and iron. The material is ejected into the interstellar medium by the explosion, and then incorporated into future generations of stars. The gas and dust which formed our solar system was enriched in life-sustaining elements via this mechanism.

This "true color" picture was made by superposing images taken on 9-10 August 1994 in three of the strongest optical emission lines: singly ionized sulfur (red), doubly ionized oxygen (green), and singly ionized oxygen (blue).

Photo credit: Jon A. Morse (STScI) and NASA



Spectroscopy of Light Nuclear Systems

- Resonances are often seen in reactions involving light nuclei ($A < 20$).
- R-Matrix Analysis can be used to analyze these systems (e.g. to predict un-measured cross sections for astrophysics or to extract spectroscopic information). We are working at O.U. to improve the computer codes used for this analysis.
- In addition to the reactions discussed elsewhere in this poster we plan to measure neutron-induced reactions on ^{13}C and ^{14}N at Los Alamos National Lab for this purpose.

Application to Medical Physics

Most cancer treatment is based on gamma rays which have a low Linear Energy Transfer (LET). Neutrons produce higher LET through the (n,p) and (n,α) reactions. The high LET radiation is more damaging to the tumor compared to the surrounding healthy tissue than low LET radiation. The high LET radiation is also more localized to the tumor area.

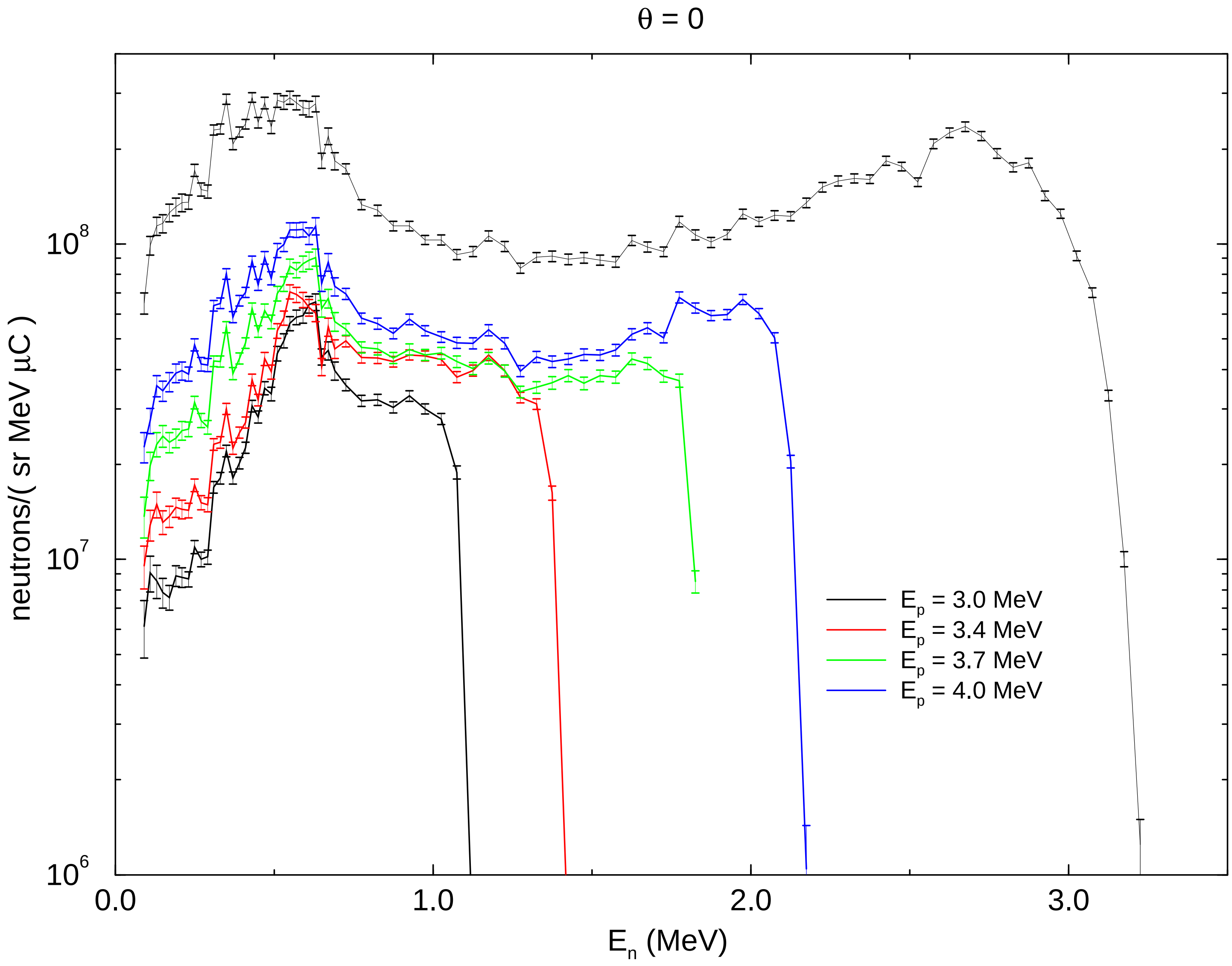
Boron Neutron Capture Therapy

Some isotopes, such as ^{10}B, have a positive Q-value and a large low energy cross section for (n,α). A low energy neutron of 0.1 MeV can produce a $\sim$2.5 MeV alpha particle. These low energy neutrons produce little damage to normal tissue. If the boron can be introduced into the tumor selectively the dose is highly concentrated.

Test of Be(p,n) as Neutron Source

- Beryllium can take large beam currents due to its high melting point of 1278° C.
- Low gamma yield. (A factor of 8-10 lower than ^{7}Li(p,n).)
- Need neutron production cross section for $E_p \leq 4$ MeV.
- O.U. Facility ideal with few background neutron.
- We have completed measurements for $3.0 \leq E_p \leq 5.0$ MeV.

Be(p,n) Thick Target Source

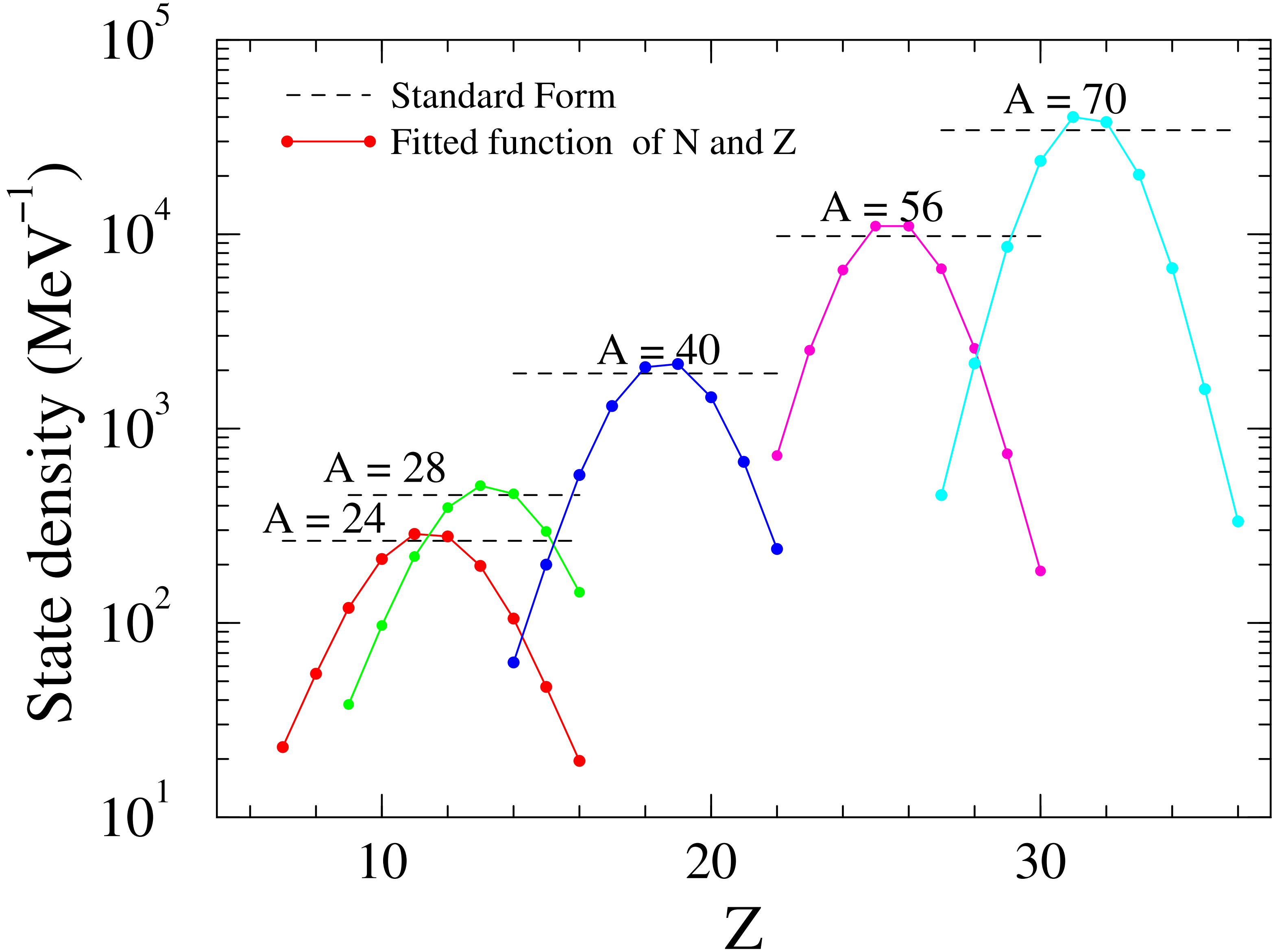


Nuclear Level Densities

- Level density is the number of excited levels of a nucleus as a function of energy
- Level Densities are needed for statistical model calculations of yields in nuclear reactions.
- They are particularly important in nuclear astrophysics and in shielding and transport calculations.
- **Facilities at O.U. are well suited for studies based on all of the above methods.** Additional measurements may take place elsewhere: Los Alamos National Lab, Oak Ridge National Lab, Hahn-Meitner Institute.

Methods of Studying Nuclear Level Densities

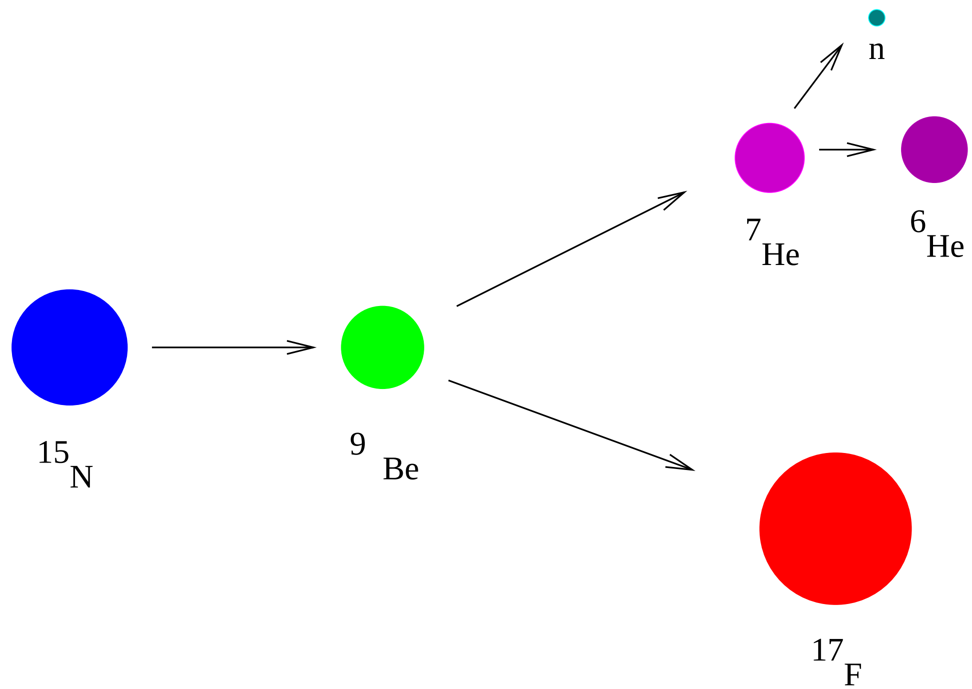
- Spectoscopy - measure excitation energies of all level in a given energy region- *only possible at low energy*
- Evaporation Spectra - measurement of the shape of the spectrum of emitted particles - *can be used even if levels overlap (level width $>$ spacing)*
- Ericson Fluctuations - Find variation in close section in fine energy steps - *can relate this to level densities*
- Theory - work on theory of level densities is also done at O.U. - currently we are working to include collective effects and studying the influence of isospin



Standard Form
Fitted function of N and Z
A = 24
A = 28
A = 40
A = 56
A = 70
State density (MeV^{-1})
10^1
10^2
10^3
10^4
10^5
10
20
30
Z

Study of Exotic Nuclei by Binary Reactions

Binary reactions are when only two nuclei are involved of the reaction in both in the begining and for the time when they are near each other. The binary reactions allow the study of very short lived states by study of a long lived companion with only the ground state stable against particle decay as shown in figure to the right.



Binary Reaction

Molecular States in the Beryllium Isotopes

The beryllium isotopes have been of great interest due to the structure of the states which have recently been observed. Rotational bands with an energy dependence of $E = k\,J(J+1)$. The moment of inertia found for these states implies a seperation of 2-3 fm between alpha for a structure where the beryllium isotopes are some number of neutrons coupled to two alpha particles.