Astrophysical Reaction Rate for the Neutron-Generator Reaction $^{13}C(\alpha,n)$ in Asymptotic Giant Branch Stars

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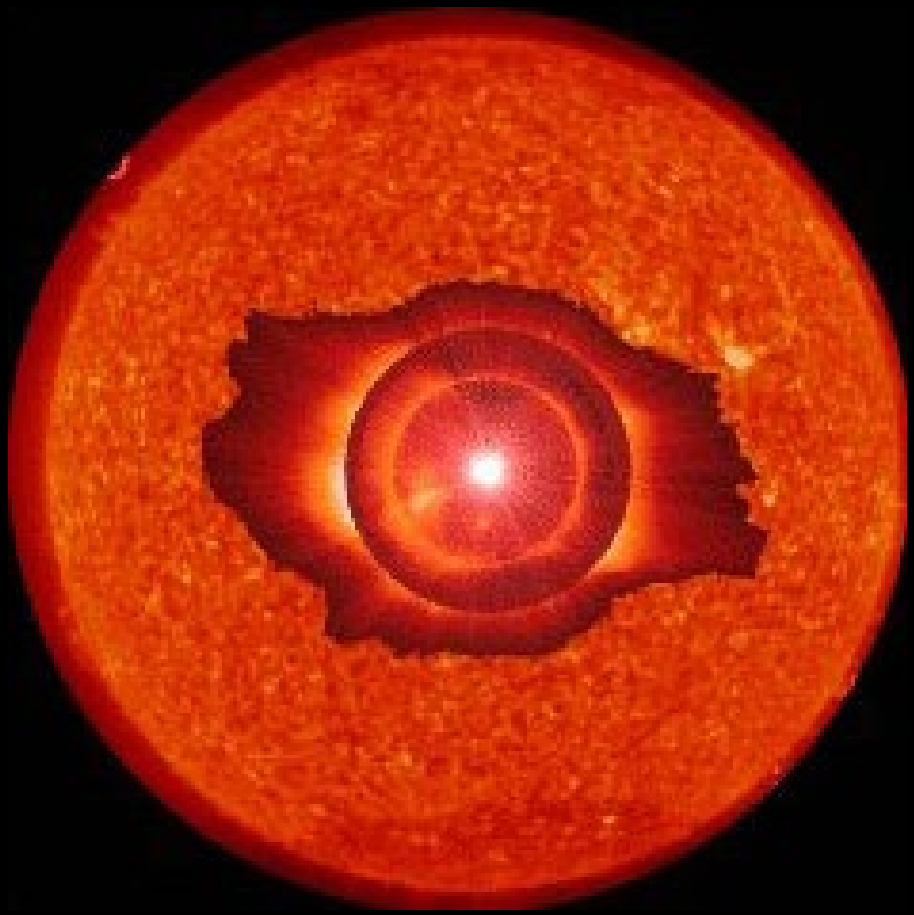
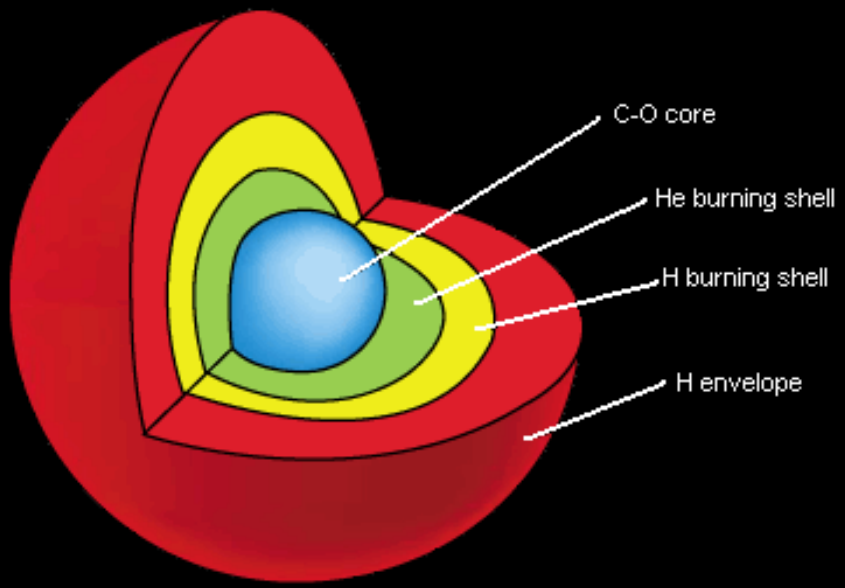
Overview

- Evolution of the universe important topic in nuclear physics
- Stellar models developed to explain AGB stars
- Importance of the reaction $^{13}C(\alpha,n)$ within AGB stars, and how it pertains to the s-process
- Direct measurement of many reactions at stellar temps is not feasible
- Development of an indirect technique to measure reaction rates



AGB Stars and the s-process

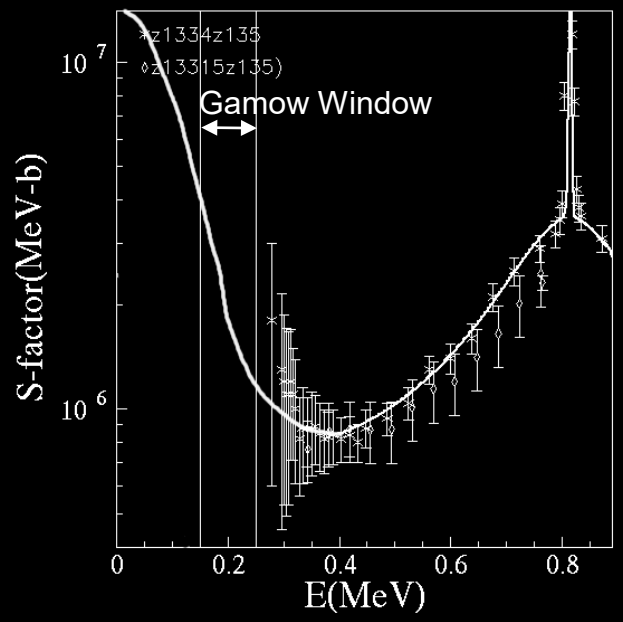


- He rich intershell main site for s-process
- He shell switches on every 100,000 yrs
- Results in a thermonuclear runaway (thermal pulse, 300 yrs)
- $^{22}Ne(\alpha,n)^{25}Mg$
- $^{13}C(\alpha,n)^{16}O$
- s-process occurs during interpulse period
- Rate and abundance
- H-burning remnants insufficient for explaining observed heavy elements

O. Straniero, R. Gallino, S. Cristallo, Nuc. Phys. A777(2006) 311

Direct Measurement of $^{13}C(\alpha,n)$

- Main neutron source for the s-process in AGB stars
- Data only goes to ~280 keV
- 1 count every 10 days for Gamow energy
- Led to indirect methods
- Asymptotic Normalization Coefficient technique
- Need to determine the ANC of the ½+, 6.36 MeV resonance in ^{17}O
- Using the ANC we can determine the Astrophysical S-factor, and then the reaction rate



$$ac + A \rightarrow c + C^*$$

$$C_{ac}^2 C_{aA}^2 \propto b_{ac}^2 b_{aA}^2 \frac{d\sigma}{d\Omega}_{\exp} * \frac{1}{b_{ac}^2 b_{aA}^2 X}$$

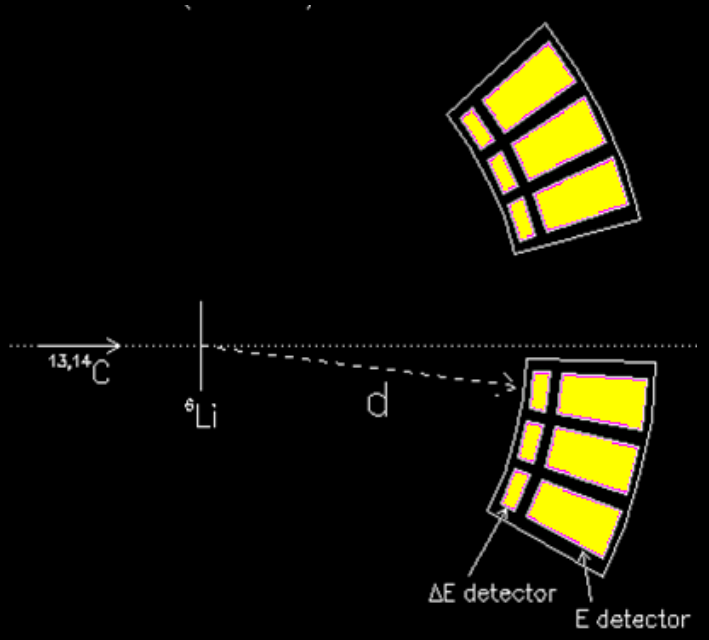
C. Angulo et al. Nucl. Phys. A656, 3 (1999)
A.M. Mukhamedzhanov, R.E. Tribble, Phys. Rev. C59, 3418 1999

Experimental Setup of $^{13}C(^{6}Li,d)$

Center of Mass Frame	Lab Frame
$^{13}C \longrightarrow \longleftarrow {}^{6}Li$	$^{13}C \longrightarrow {}^{6}Li$
$\longleftarrow {}^{17}O \quad d \longrightarrow$	$^{17}O \rightarrow \quad d \longrightarrow$

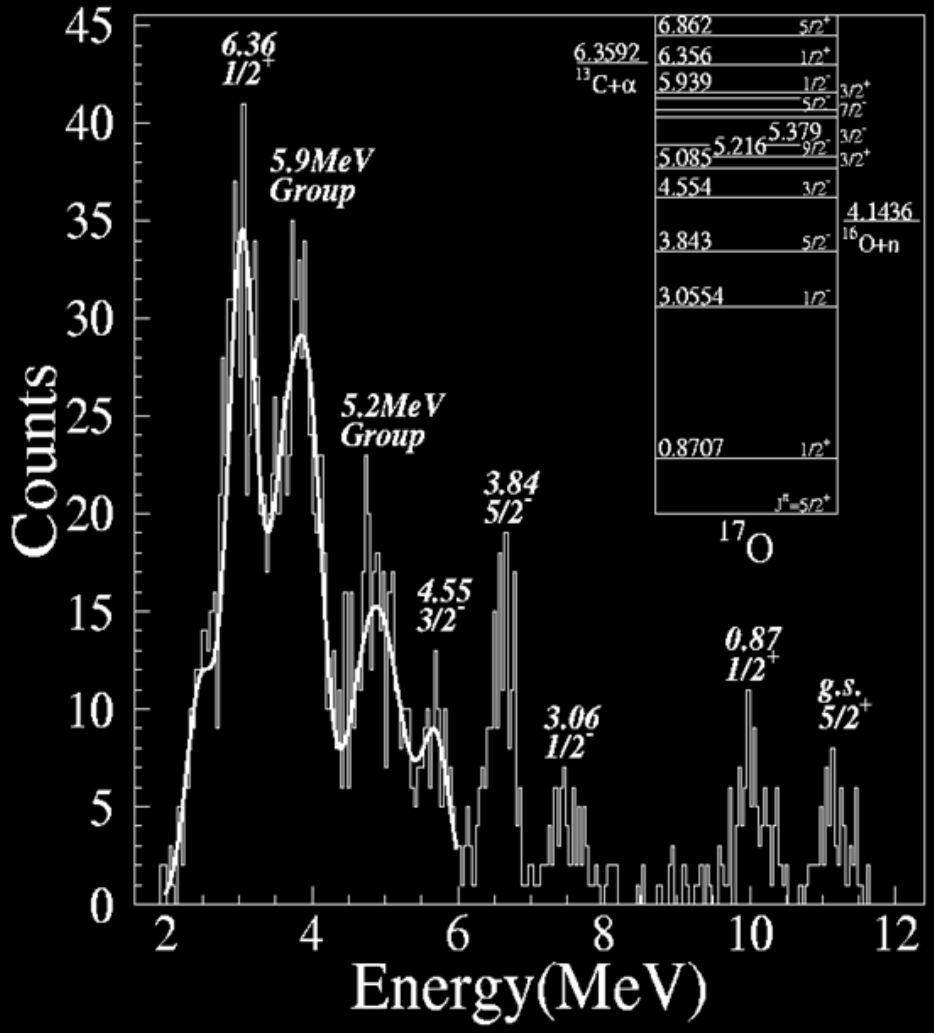
- Inverse kinematics to measure at very low energies
- Cross section has max at 180˚ in CM
- 0˚ for deuterons in Lab Frame
- Si, ΔE-E telescopes
- Identify deuterons from other charged products

- Sub-Coulomb energies were 8 and 8.5 MeV
- Lowest possible energy for the targets and detectors available



E.D. Johnson et al, PRL 97 192701 (2006)

Results of $^{13}C(^{6}Li,d)$



- Spectrum of deuterons at 6˚, and 8.5 MeV
- State of interest: 6.36 MeV ½+
- Experimental resolution is ~300 keV

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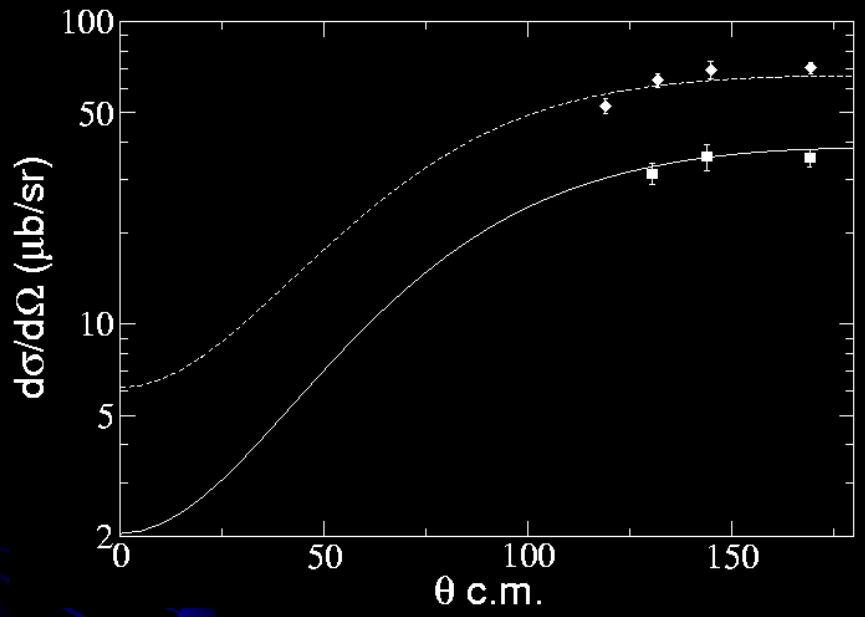
Angular Distributions

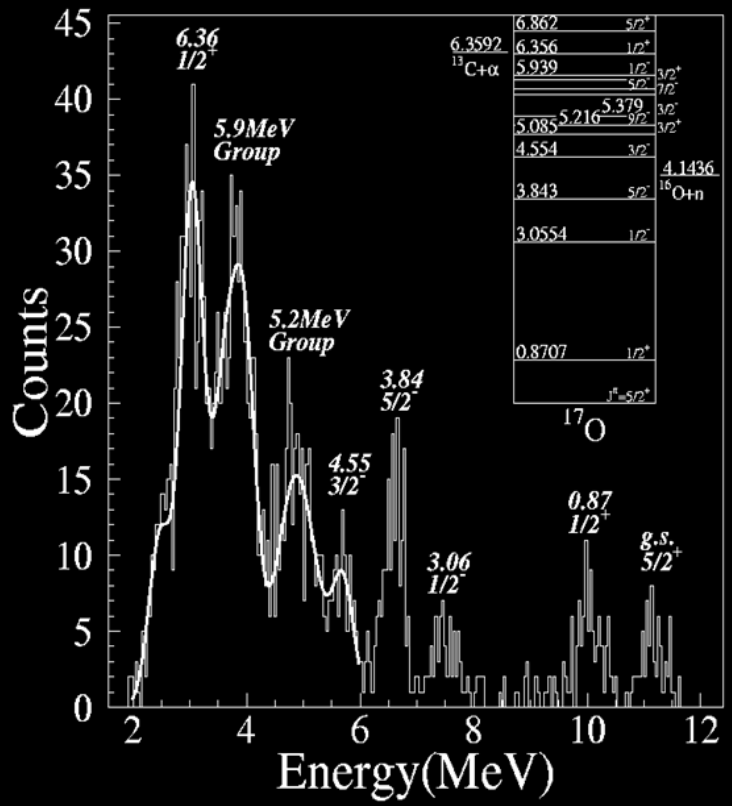


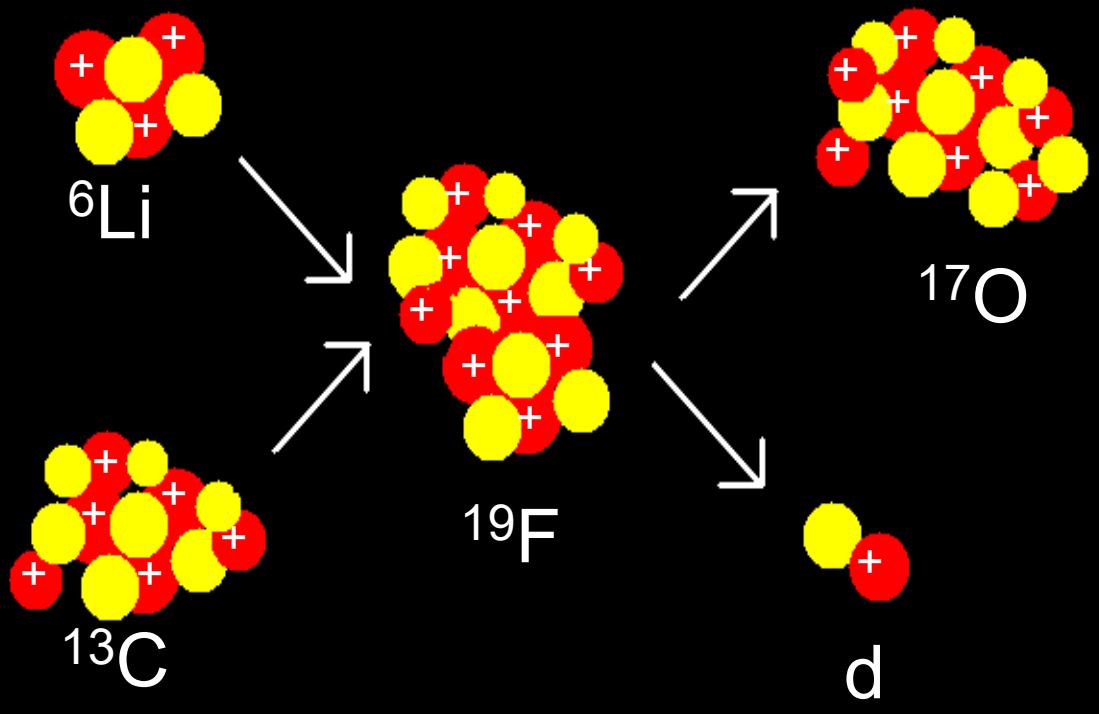
- Angular Distributions data and curves for 8 & 8.5 MeV
- Absolute normalization done with ^{6}Li(p,p), since targets were prepared under vacuum
- DWBA approach was used
- Nuclear potentials are unknown
- Verified that several potentials produce similar results
- Uncertainty in calculated cross section is <20%

E.D. Johnson et al, PRL 97 192701 (2006)

Compound Nucleus Contribution

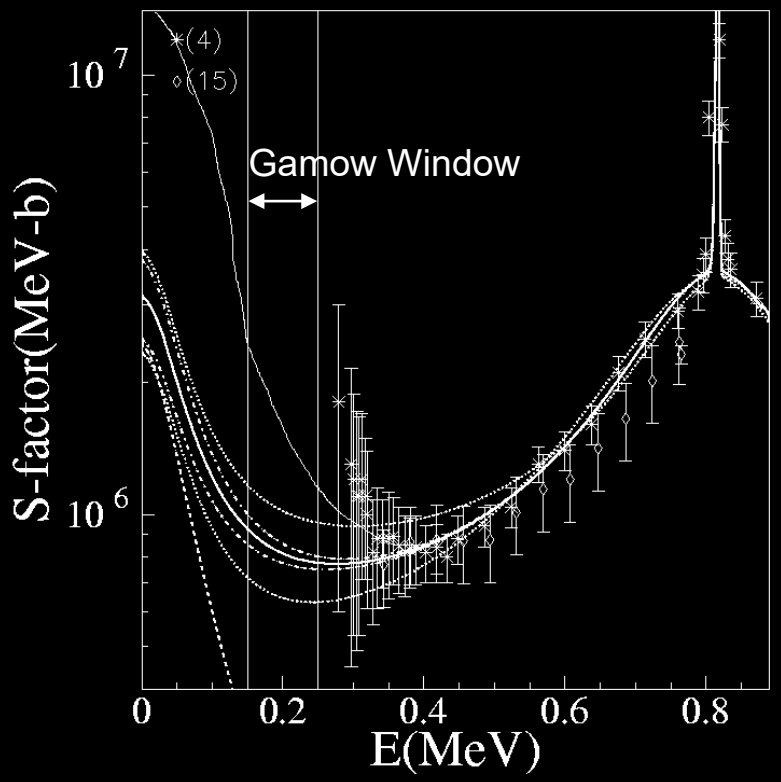
- 1st excited state in ^{17}O
- Same spin-parity as our state of interest
- 4% of total c.s.
- Confirmed with code EMPIRE
- Use of DWBA is OK





R-Matrix Approach

- Determine contribution of ½+ ANC to S(0) factor
- S(0) 10 x's smaller than NACRE
- 2-channel R-Matrix approach
- ½+, 6.36 MeV contribution shown as dashed curve
- Solid curve best R-matrix fit
- Dash-dotted equal uncertainty ~25%
- Constant non-res contribution of ~0.4*10^6 MeV*b to fit low energy data



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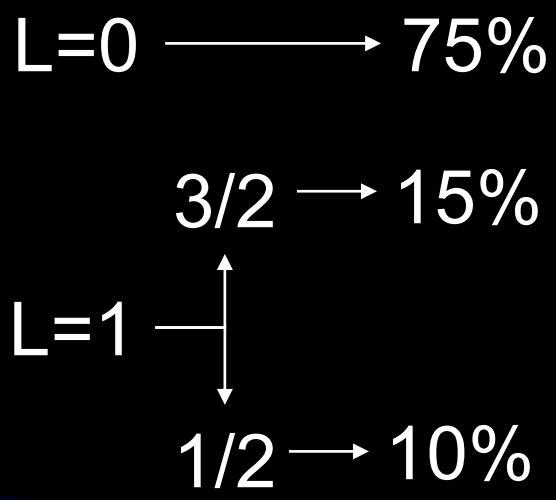
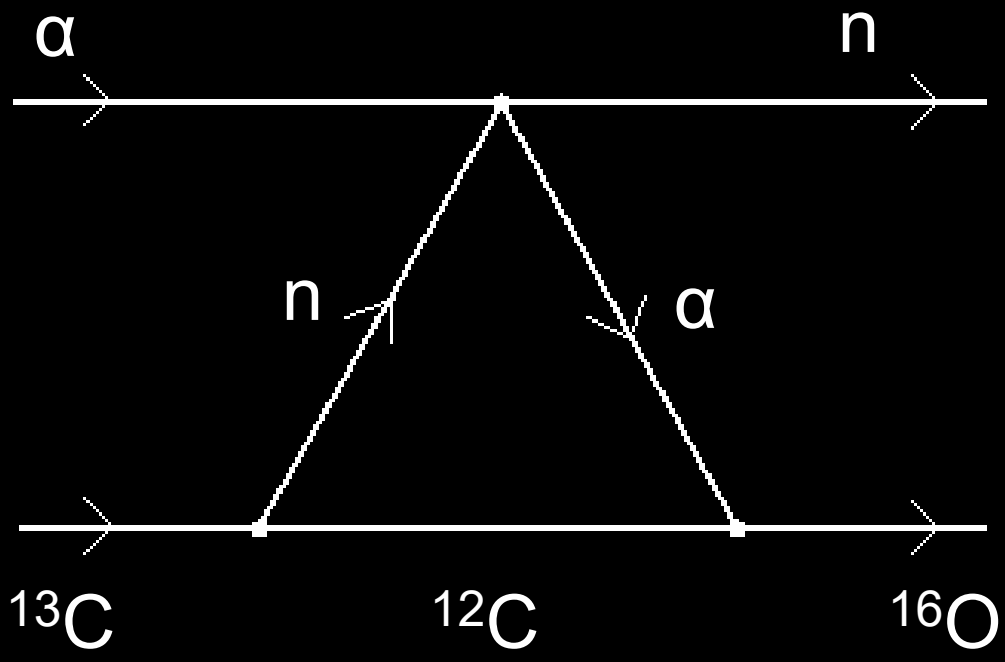
$^{13}C(\alpha,n)$ Direct Reaction

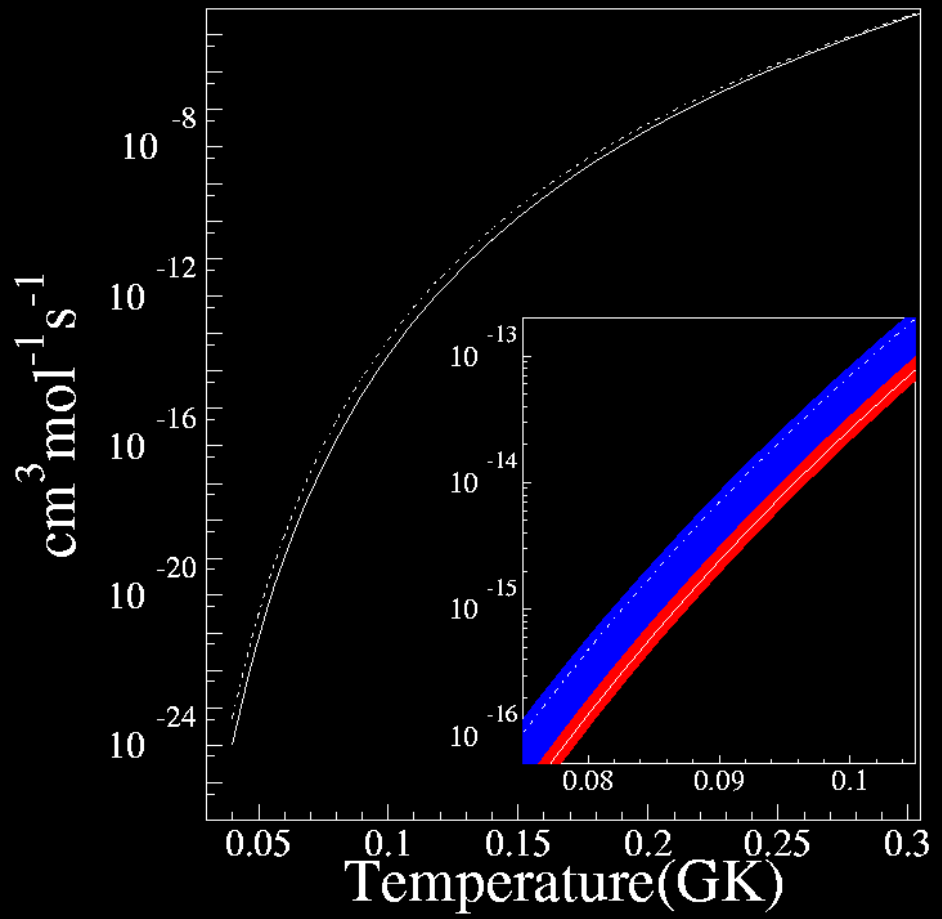




- Constant represents direct reaction cross section not included in R-matrix analysis
- Nearly constant for low energy region
- L=0 waves don't interfere with R-matrix
- L=1 waves will interfere, but only 10%
- Interference is within error

$^{13}C(\alpha,n)$ Reaction Rate

- Our rate (solid) and NACRE rate (dash-dotted)
- Curves identical for T > 0.3 GK
- Rate is 3x's smaller where s-process occurs in AGB stars
- Uncertainty reduced from 300% (blue) to 25% (red)



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Acknowledgments

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