Topics in stellar He burning

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Topics in Stellar He-Burning

The example $^{14}N(\alpha,\gamma)^{18}F$

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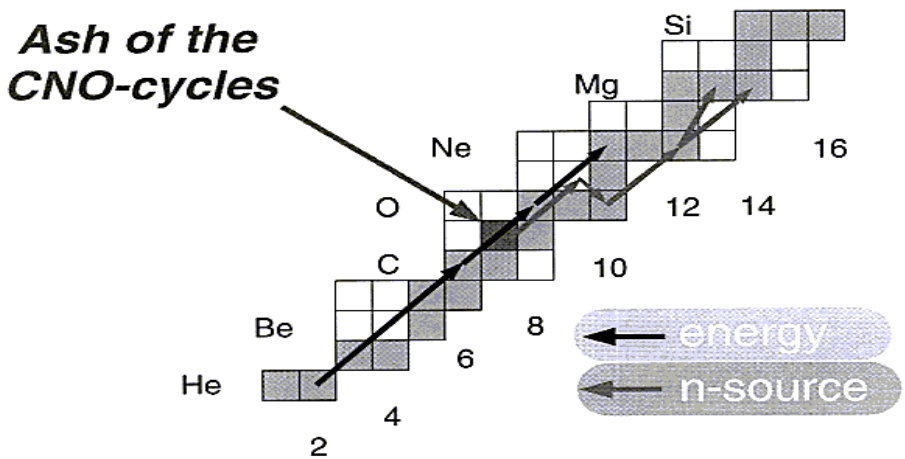
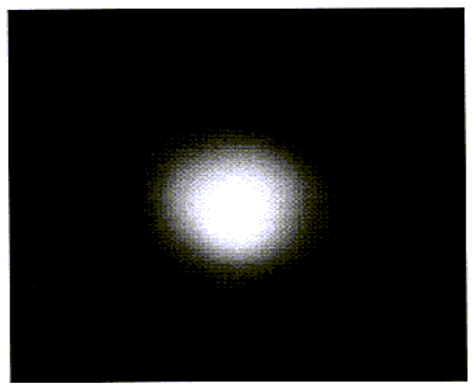
Technik und Umwelt
Mitglied der HGF - Hermann von Helmholtz-Gemeinschaft Deutscher Forschungszentren

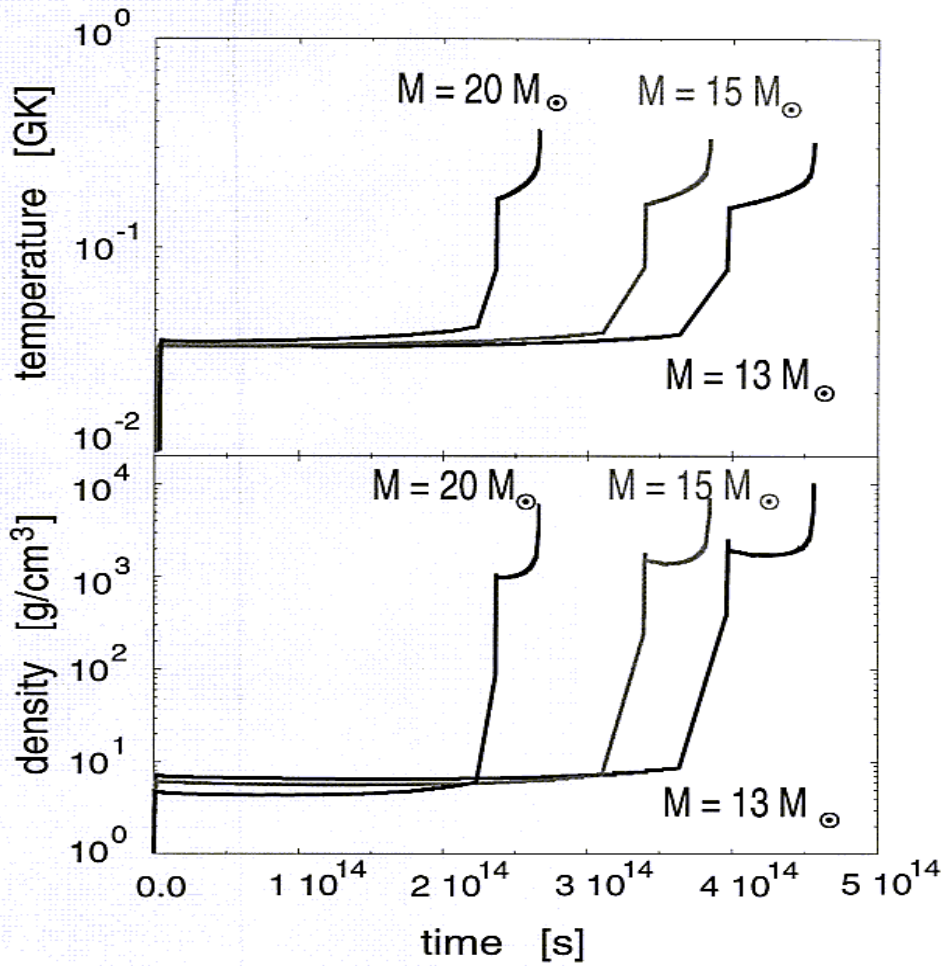
Key reactions during core He-burning



Hubble Space Telescope: Betelgeuse

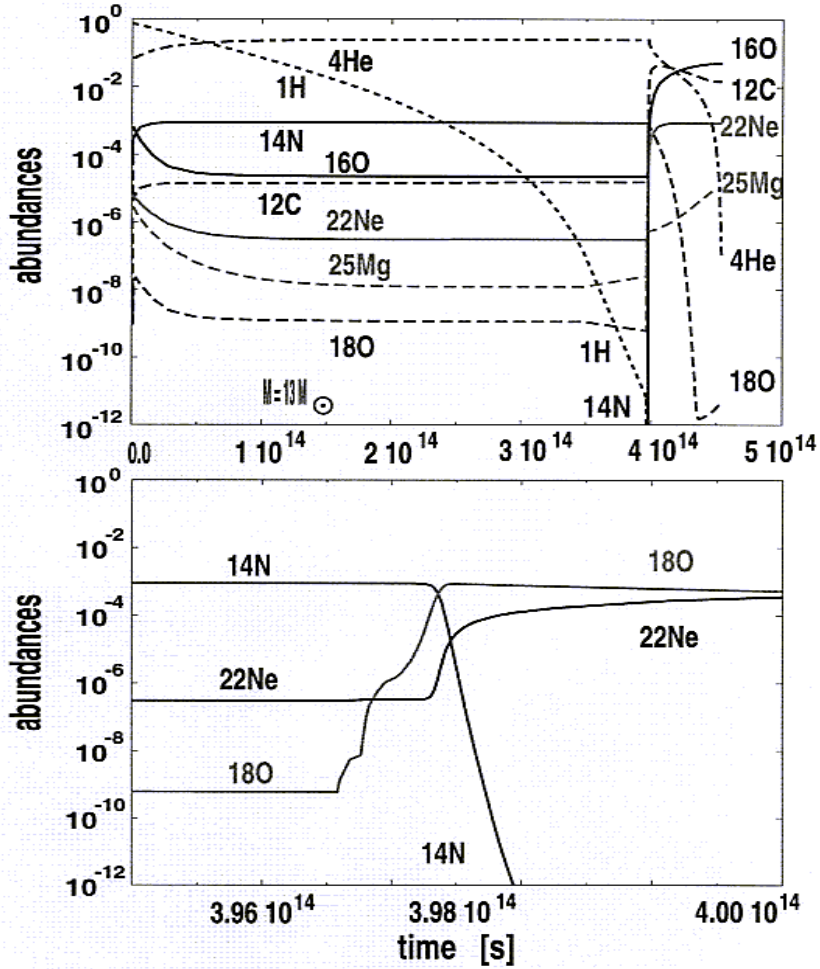


Time Dependence of Temperature and Density for Massive Stars

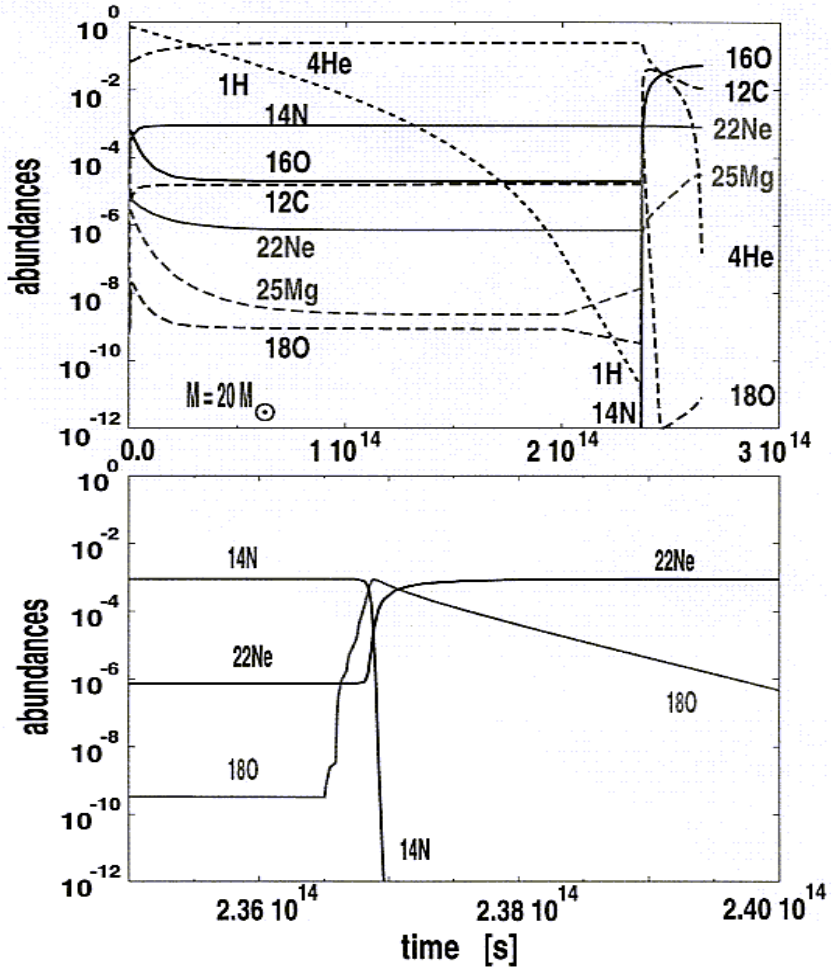


Courtesy Alessandro Chieffi

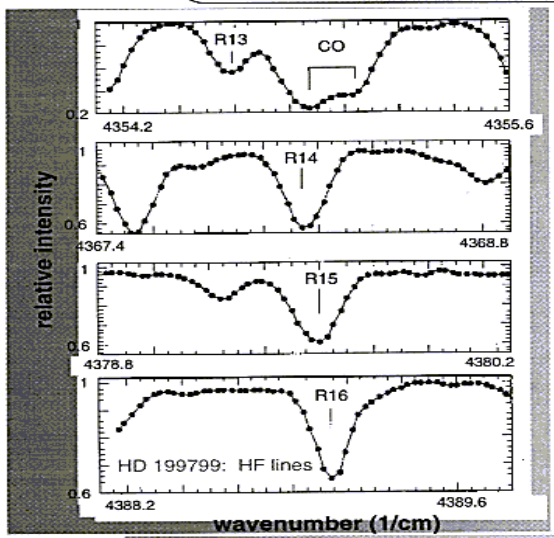
13 solar masses



20 solar masses



^{19}F-production in AGB stars



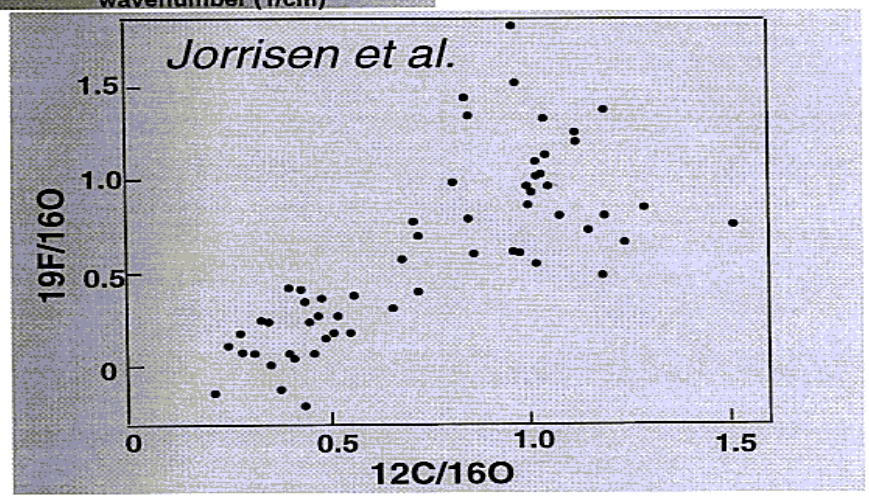
Observation of Fluorine abundances in surface of red giants

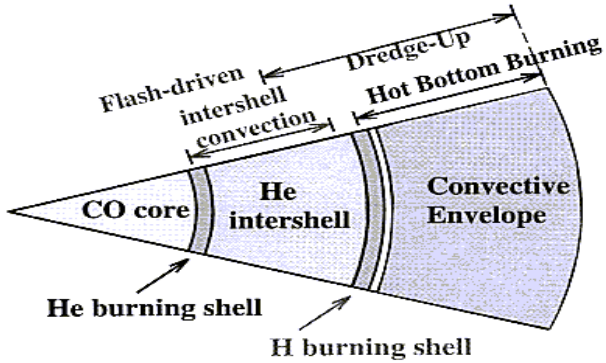
+

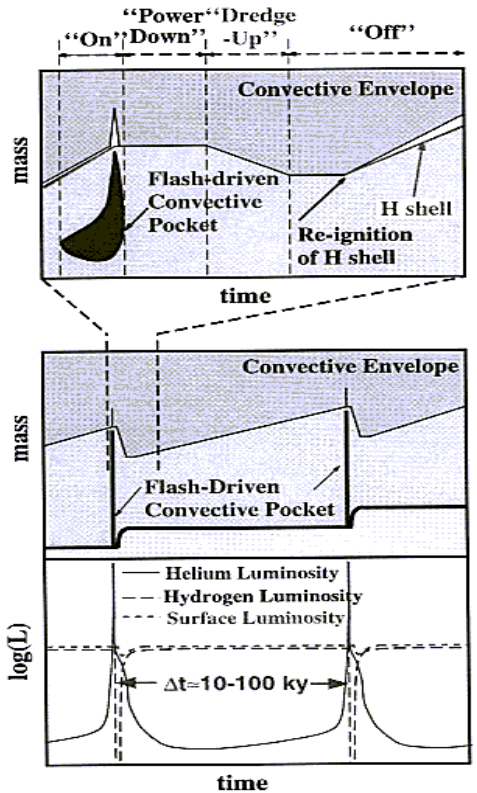
Correlation with 12C abundance

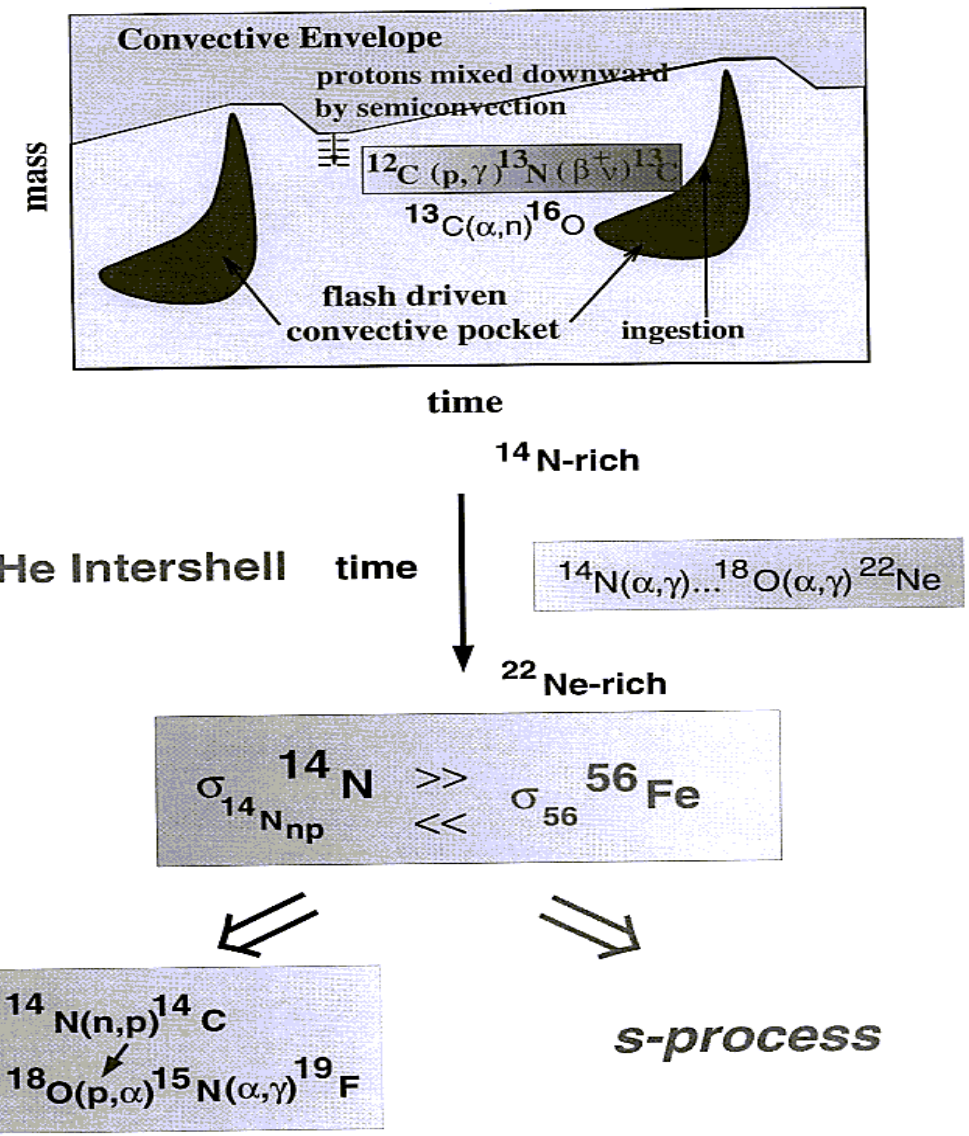
↓

Fluorine production in thermally pulsing AGB stars

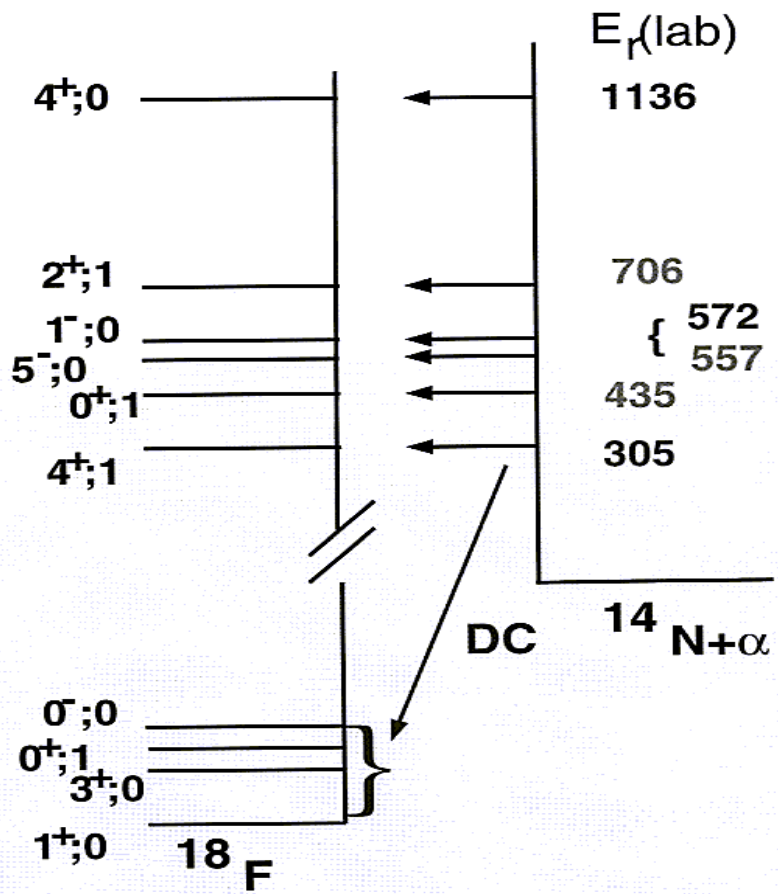



Flash-driven
intershell
convection
Dredge-Up
Hot Bottom Burning
CO core
He
intershell
Convective
Envelope
He burning shell
H burning shell


"On"
"Power
Down"
"Dredge
-Up"
"Off"
Convective Envelope
mass
Flash-driven
Convective
Pocket
H shell
Re-ignition
of H shell
time
Convective Envelope
mass
Flash-Driven
Convective Pocket
Helium Luminosity
Hydrogen Luminosity
Surface Luminosity
log(L)
Δt≈10-100 ky
time


Convective Envelope
protons mixed downward
by semiconvection
$^{12}C\,(p,\gamma)^{13}N\,(\beta^{+}\nu)^{13}C$
$^{13}C(\alpha,n)^{16}O$
flash driven
convective pocket
ingestion
mass
time
^{14}N-rich
He Intershell
time
$^{14}N(\alpha,\gamma)...^{18}O(\alpha,\gamma)^{22}Ne$
^{22}Ne-rich
$\sigma_{^{14}N_{np}}\ ^{14}N \gg \sigma_{56}\ ^{56}Fe$
$^{14}N(n,p)^{14}C$
$^{18}O(p,\alpha)^{15}N(\alpha,\gamma)^{19}F$
s-process

Contributions to the $^{14}N+\alpha$ Rate



Previous Experiments

Absolute Resonance Strength $\omega\gamma$

- measured resulting ^{18}F activity
- ∞ -thick target

E_r	$\omega\gamma$ *	$\omega\gamma$ *	
559	95		μeV
1140	35	22	meV
Couch et al.		Parker	

* *renormalized to stopping powers of Ziegler*

Experimental Setup

50-80 μA
α - beam

KN accelerators at
Karlsruhe and Notre Dame

Energy calibration: $^{27}Al(p,\gamma)^{28}Si$

TiN targets
50 μg/cm2
Ta backing

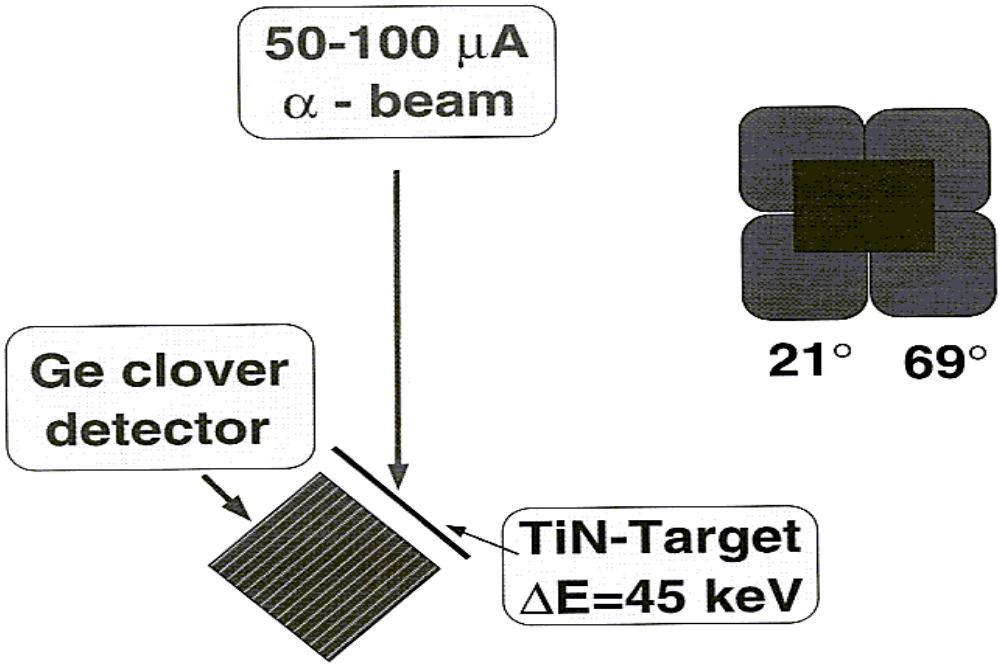
TiN sputtered onto Ta-backings
thanks to Institut für
Materialforschung, FZK

Stoichiometry: **Ti:N = 1 ± 0.02**
Target thickness: **45 keV at E = 1.14 MeV**

extremely stable

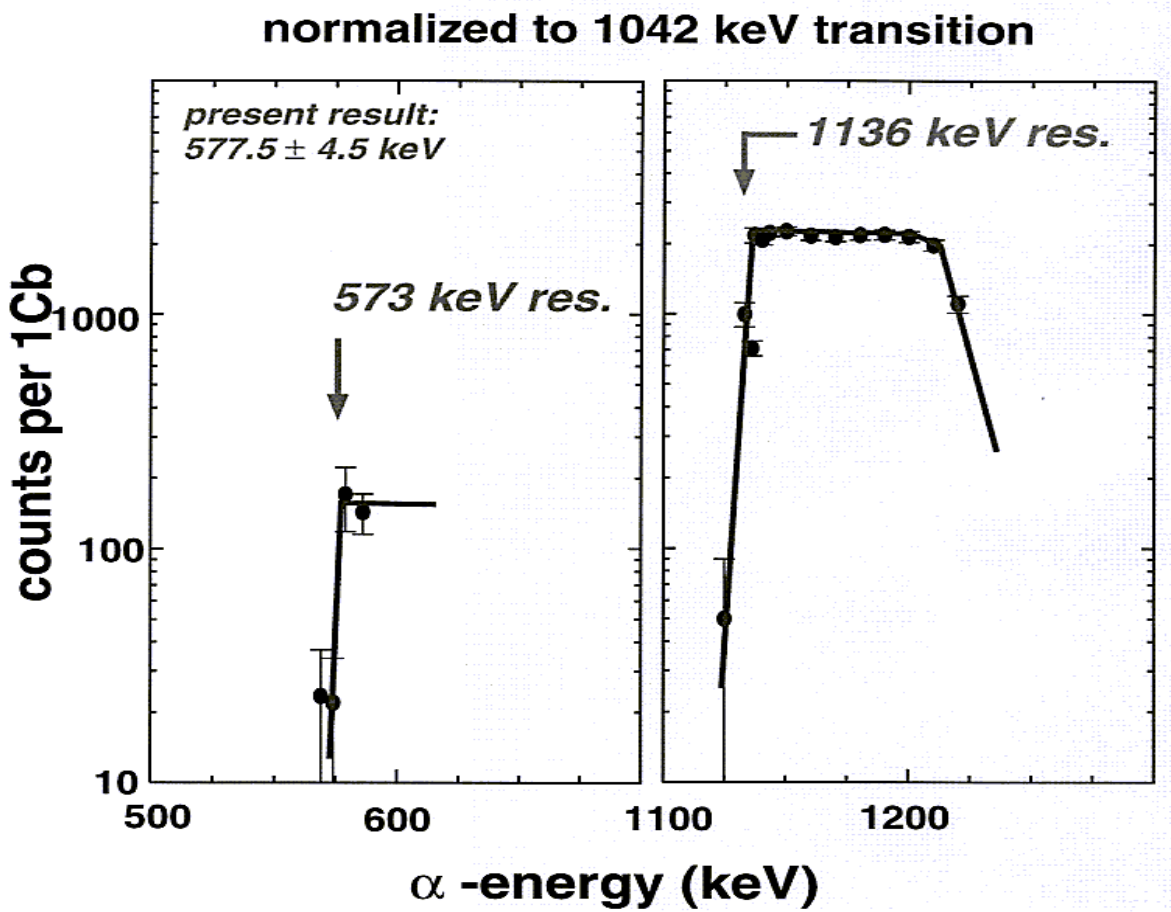
No change in yield observed after an accumulated charge of 11 Coulomb!

Experimental Setup



Advantage: high efficiency
Doppler shift correction
angular distribution
lifetime information

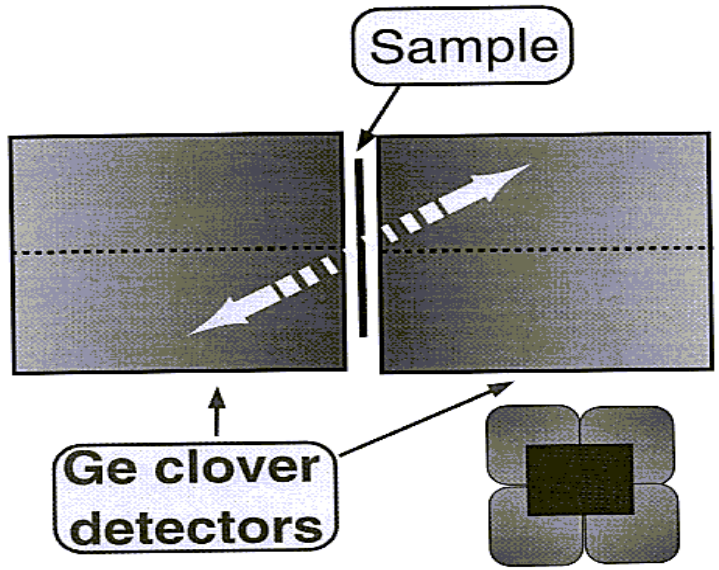
Excitation Curves



Couch et al.: 559 keV from literature

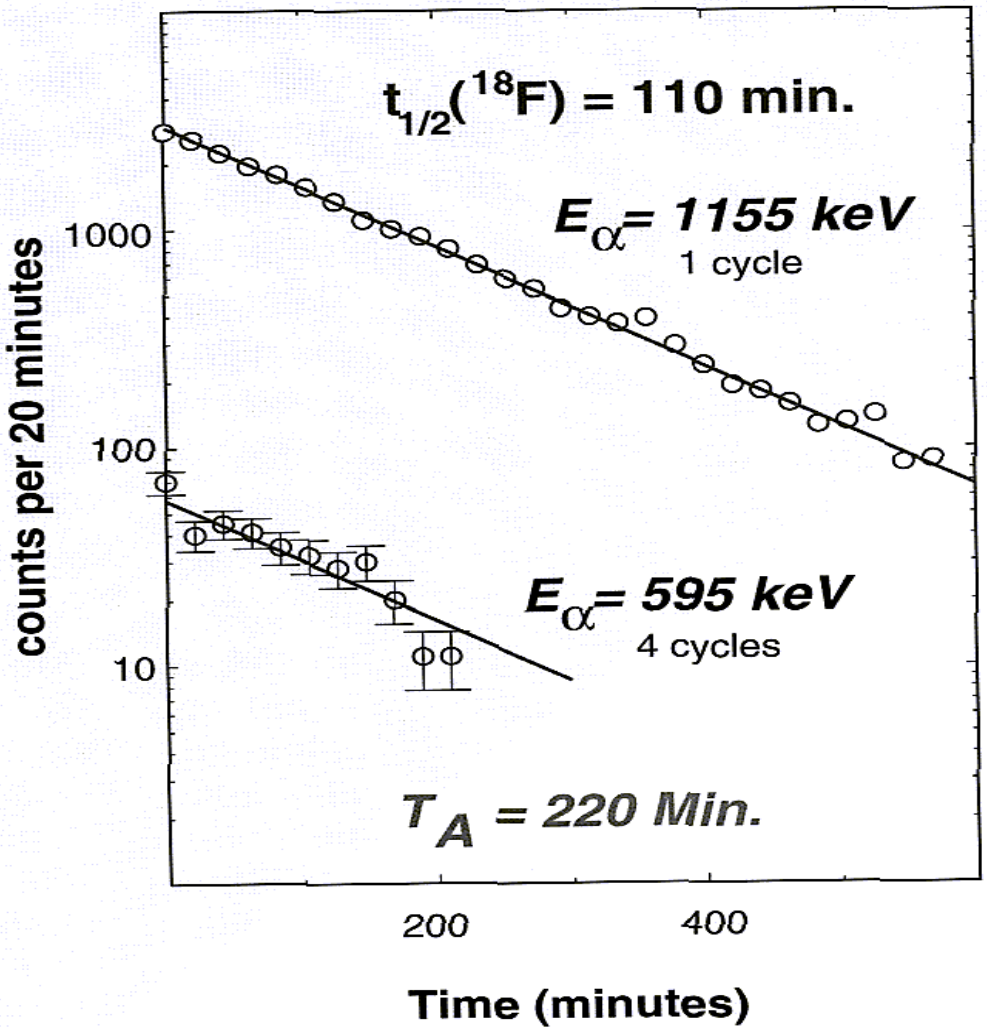
Experimental Setup

511keV coincidences



Advantage: **high efficiency** =3.46%
(large detector volume)
low background =0.6/h
(high energy resolution)
(granularity: directional correlation!)

Decay Curve


$t_{1/2}(^{18}F)$ = 110 min.
E_α= 1155 keV
1 cycle
E_α= 595 keV
4 cycles
T_A = 220 Min.
counts per 20 minutes
1000
100
10
200
400
Time (minutes)

Resulting $\omega\gamma$

1136 keV resonance:

present: 21.0±0.3 meV

Parker : 22.4±1.0 meV

Couch : 35.1±3.2 meV

21.1±1.5 meV

7% uncertainty in dE/dx

573 keV resonance:

absolute strength

present: 45± 3 μeV

Couch : 96±14 μeV

relative yield

prompt: 275 ± 77

activity: 256 ± 15

Couch : 200 ± 35

46±4 μeV

Low Energy Contribution ?

305 keV resonance

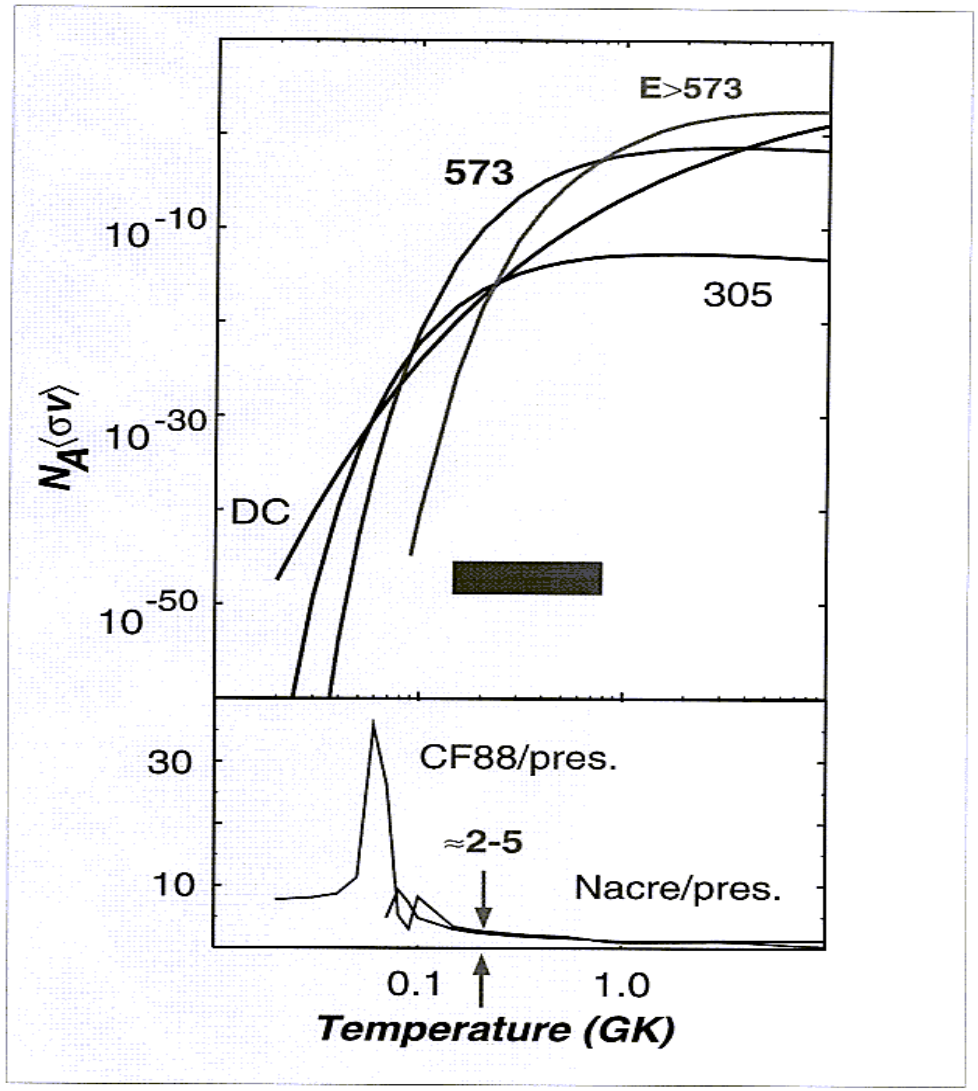
$$\omega\gamma \approx \omega\Gamma_\alpha = 3\, f_{iso}\theta_\alpha\Gamma_{sp}$$

present	Couch (NACRE)
E = 305 keV	E = 310 (305) keV
$f_{iso} = 0.001$	$f_{iso}\theta_\alpha = 0.001$
$\theta_\alpha = 0.03$	
$\Gamma_{sp} = 2.85\ 10^{-13}$ eV	$\Gamma_{sp} = 2.8\ 10^{-12}$ eV
$\omega\gamma = 2.57\ 10^{-17}$	$\omega\gamma = 8.3\ 10^{-15(16)}$

non-resonant

$S_{DC} = 0.085$ MeV-b	$S_{DC} = 0.1$ MeV-b
$S_{tail} \approx 0.006$ MeV-b	$S_{tail} = 0.6$ MeV-b
$\Gamma \approx \Gamma(exp.)_\gamma = 10$ *meV*	$\Gamma \approx \Gamma(guess)_\gamma = 1$ *eV*

Reaction Rate



Conclusion:

- *The present results are in good agreement with the resonance strength of Parker. This together with a raised energy for the 573 keV resonance reduces the reaction rate of $^{14}N(\alpha,\gamma)^{18}F$ by approximately a factor of 2-5 the temperatures of interest.*

- *The new rate has NO influence on the production of ^{22}Ne during core He-burning in massive stars because of the long time scale.*

- *New ABG model calculations are necessary to evaluate the possible influence of the new rate on the Fluorine production in AGB stars (interplay of reaction rates and mixing).*