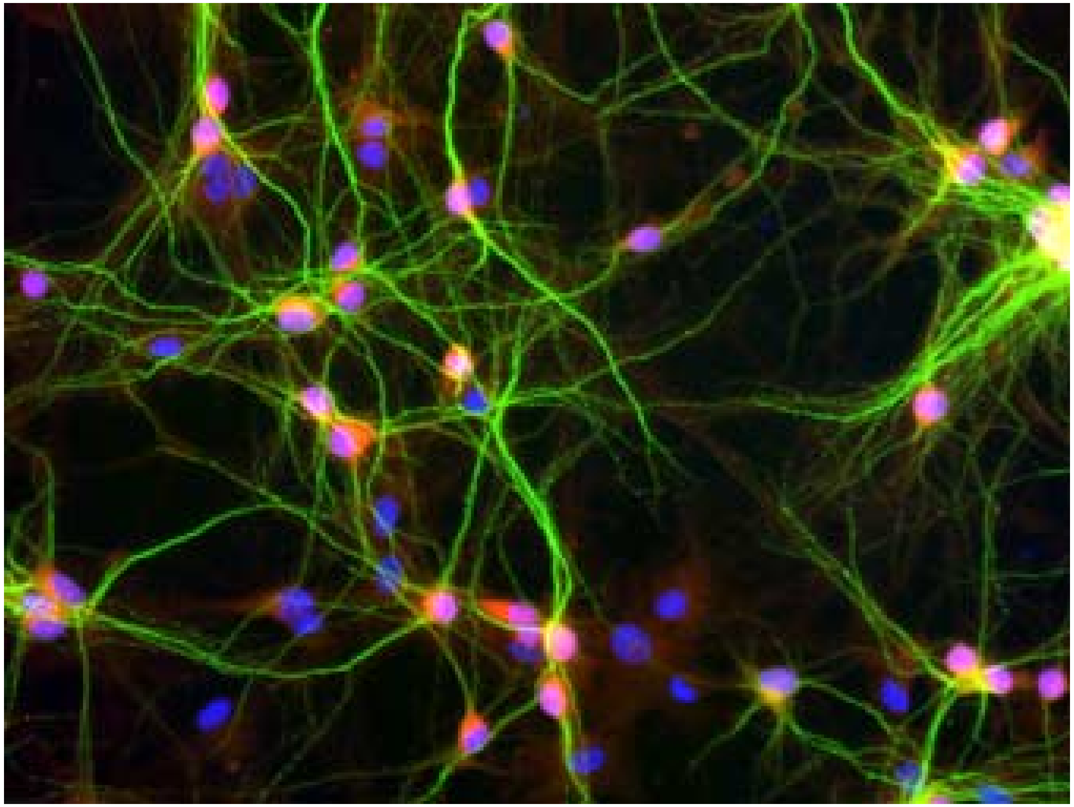
Nuclear reaction network calculations

Anuj Parikh (TUM)



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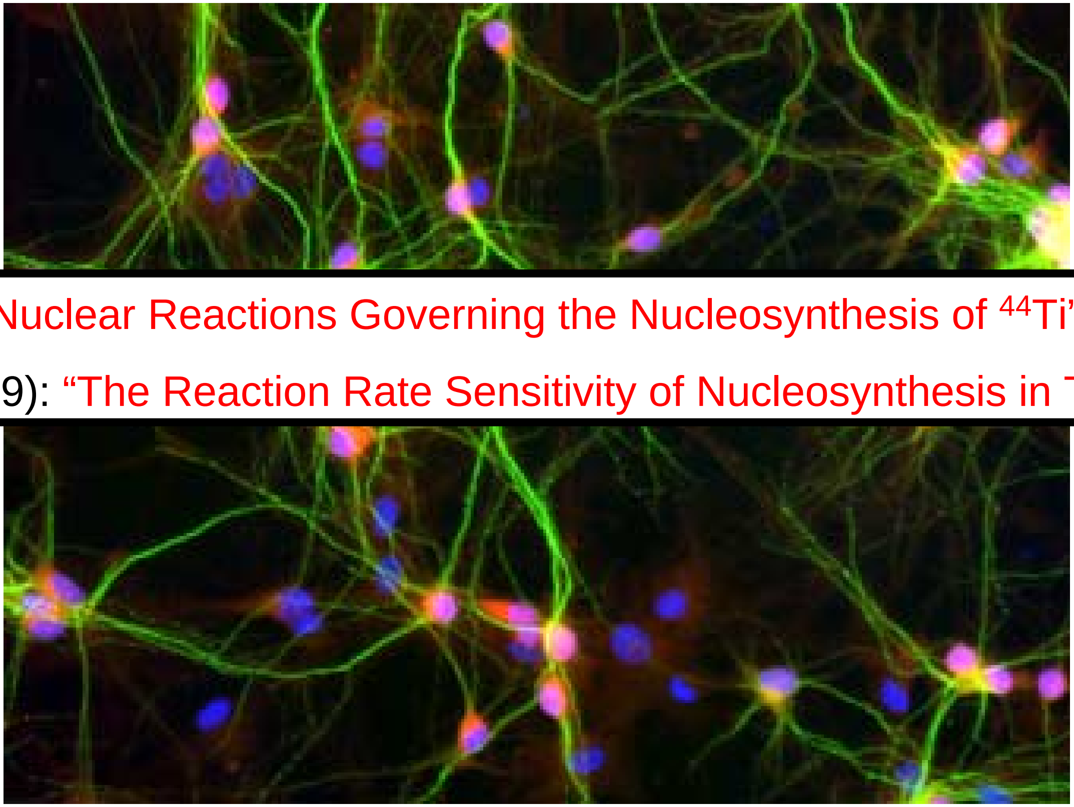

The et al. (1998): "Nuclear Reactions Governing the Nucleosynthesis of ^{44}Ti"

Hoffman et al. (1999): "The Reaction Rate Sensitivity of Nucleosynthesis in Type II Supernovae"

^{44}Ti: Nuclear network calculations

The et al. (1998): "Nuclear reactions governing the nucleosynthesis of ^{44}Ti"

- post-processing sensitivity study

- single zone with $T_i = 5.5$ GK, $\rho_i = 10^7$ g/cm^3 → adiabatic expansion of ^{28}Si + ^{30}Si matter
- $\rho \propto T^3$, ρ_i declines exponentially in time
- T → 0.25 GK (charged particle freeze-out)
- same conditions as Woosley and Hoffman (1991) (i.e. Si burning → alpha-rich freeze-out)

- repeated for 3 values of η = 0 (He core), = 0.002 (C/O core); = 0.006 (Si core)

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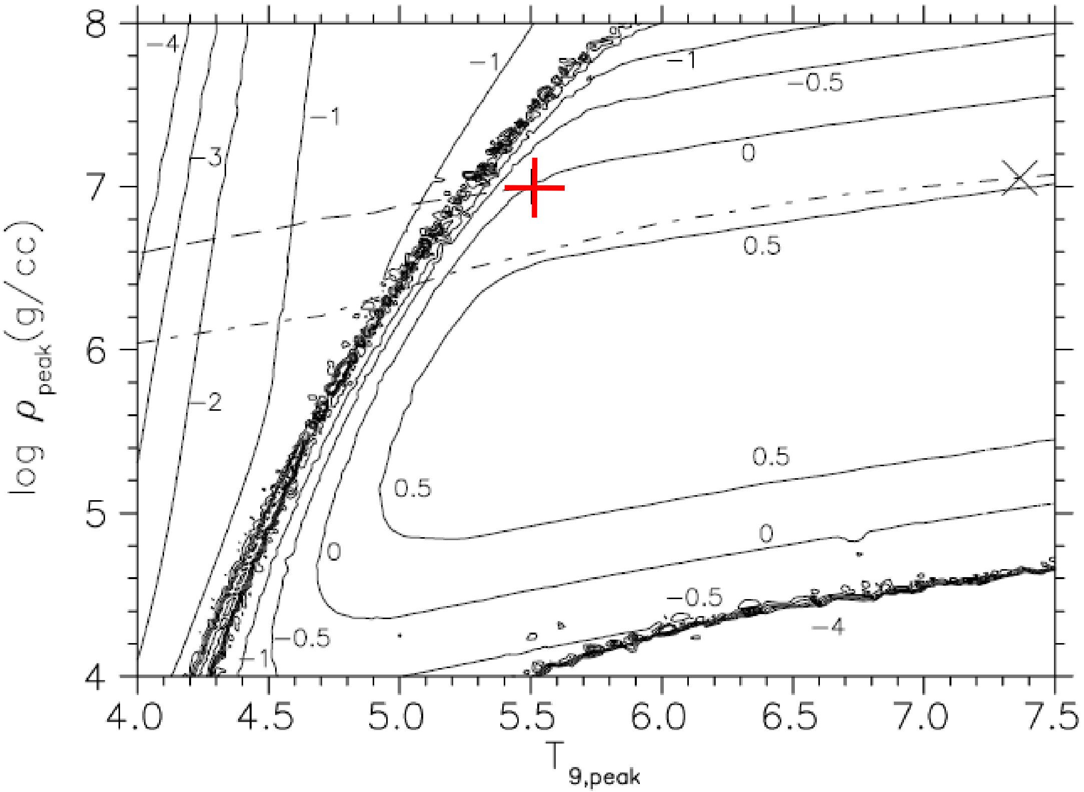

+ $X_f = 2x\ 10^{-4}$

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- reaction network: H – Br (Z = 1 – 35)

(α,γ), (α,p), (α,n), (p,γ), (p,n), (n,γ) reactions

experimental rates when possible; majority (esp. near ^{44}Ti) from SMOKER

multiplying rates individually by uniform, T-independent factors of 100 / 0.01
→ look at effects on final yields of ^{44}Ti

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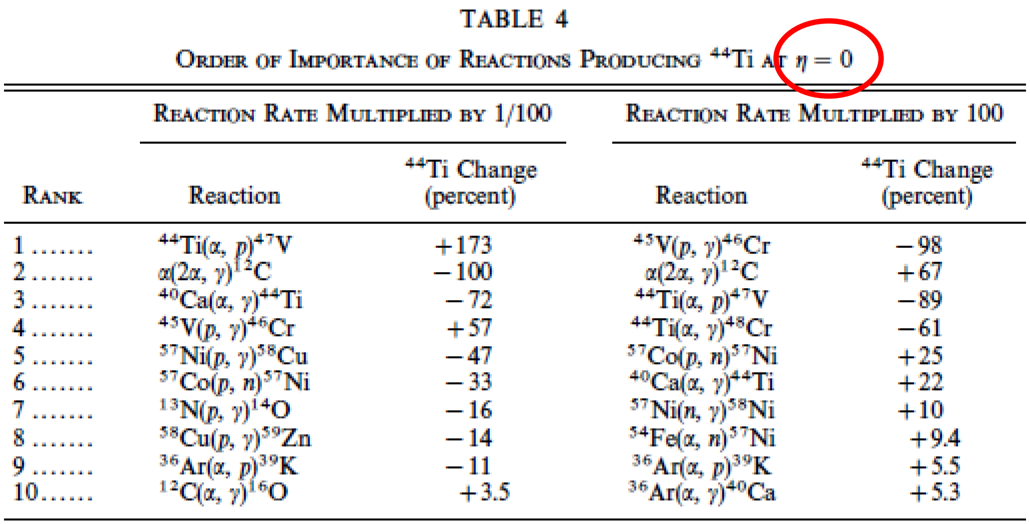

TABLE 4

ORDER OF IMPORTANCE OF REACTIONS PRODUCING ^{44}Ti AT $\eta = 0$

	REACTION RATE MULTIPLIED BY 1/100		REACTION RATE MULTIPLIED BY 100	
RANK	Reaction	^{44}Ti Change (percent)	Reaction	^{44}Ti Change (percent)
1	^{44}Ti(α, p)^{47}V	+173	^{45}V(p, γ)^{46}Cr	−98
2	α(2α, γ)^{12}C	−100	α(2α, γ)^{12}C	+67
3	^{40}Ca(α, γ)^{44}Ti	−72	^{44}Ti(α, p)^{47}V	−89
4	^{45}V(p, γ)^{46}Cr	+57	^{44}Ti(α, γ)^{48}Cr	−61
5	^{57}Ni(p, γ)^{58}Cu	−47	^{57}Co(p, n)^{57}Ni	+25
6	^{57}Co(p, n)^{57}Ni	−33	^{40}Ca(α, γ)^{44}Ti	+22
7	^{13}N(p, γ)^{14}O	−16	^{57}Ni(n, γ)^{58}Ni	+10
8	^{58}Cu(p, γ)^{59}Zn	−14	^{54}Fe(α, n)^{57}Ni	+9.4
9	^{36}Ar(α, p)^{39}K	−11	^{36}Ar(α, p)^{39}K	+5.5
10......	^{12}C(α, γ)^{16}O	+3.5	^{36}Ar(α, γ)^{40}Ca	+5.3

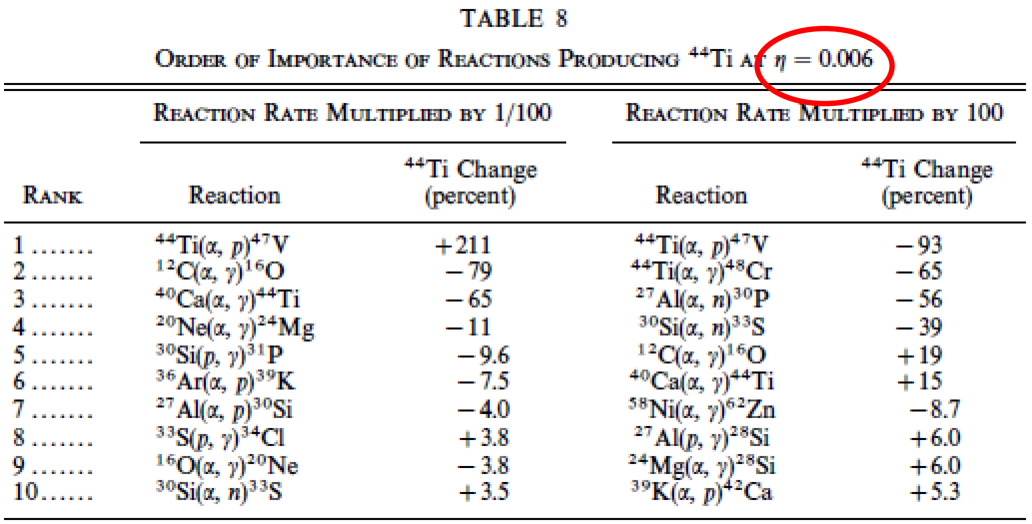

TABLE 8

ORDER OF IMPORTANCE OF REACTIONS PRODUCING ^{44}Ti AT $\eta = 0.006$

	REACTION RATE MULTIPLIED BY 1/100		REACTION RATE MULTIPLIED BY 100	
RANK	Reaction	^{44}Ti Change (percent)	Reaction	^{44}Ti Change (percent)
1	^{44}Ti(α, p)^{47}V	+211	^{44}Ti(α, p)^{47}V	−93
2	^{12}C(α, γ)^{16}O	−79	^{44}Ti(α, γ)^{48}Cr	−65
3	^{40}Ca(α, γ)^{44}Ti	−65	^{27}Al(α, n)^{30}P	−56
4	^{20}Ne(α, γ)^{24}Mg	−11	^{30}Si(α, n)^{33}S	−39
5	^{30}Si(p, γ)^{31}P	−9.6	^{12}C(α, γ)^{16}O	+19
6	^{36}Ar(α, p)^{39}K	−7.5	^{40}Ca(α, γ)^{44}Ti	+15
7	^{27}Al(α, p)^{30}Si	−4.0	^{58}Ni(α, γ)^{62}Zn	−8.7
8	^{33}S(p, γ)^{34}Cl	+3.8	^{27}Al(p, γ)^{28}Si	+6.0
9	^{16}O(α, γ)^{20}Ne	−3.8	^{24}Mg(α, γ)^{28}Si	+6.0
10......	^{30}Si(α, n)^{33}S	+3.5	^{39}K(α, p)^{42}Ca	+5.3

Reaction-rates to which ^{44}Ti is MOST sensitive:

- ^{44}Ti(a,p)^{47}V
- ^{45}V(p,γ) ^{46}Cr
- ^{40}Ca(a,γ) ^{44}Ti
- ^{44}Ti(a,γ) ^{48}Cr
- ^{27}Al(a,n) ^{30}P
- ^{30}Si(a,n) ^{33}S

Is a factor 100 justified? Probably not…

^{44}Ti: Nuclear network calculations

Hoffman et al. (1999): “The Reaction Rate Sensitivity of Nucleosynthesis in Type II Supernovae”

- 1-D hydro code (KEPLER), co-processing with 200 isotope network (H – Kr)

- induced explosions of 15 and 25 M_{sol} stars: inward, outward moving piston (WW95)
  - → v_{piston} causes KE_f of ejecta ~ 1 – 2 foe
  - → piston position + energy gives mass cut

- reaction network: experimental when possible
  - → 2 sets of theoretical HF rates (SMOKER, CRSEC) for heavier masses

- ejected yields from using these 2 different theoretical reaction libraries compared

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  - → 2 sets of theoretical HF rates (SMOKER, CRSEC) for heavier masses

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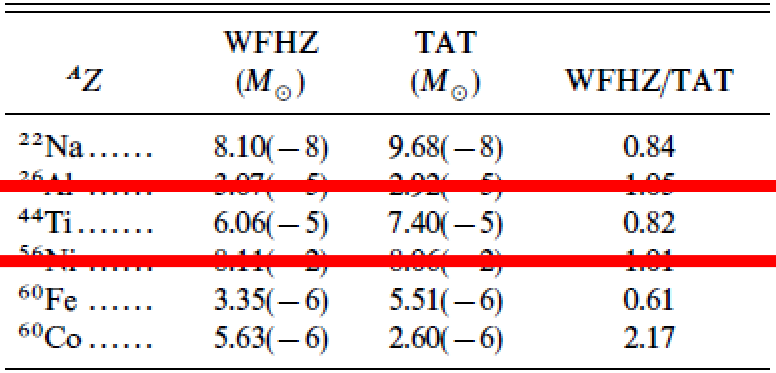
Ejected yields :15 M_{sol} model



^{A}Z	WFHZ ($M_{\odot}$)	TAT ($M_{\odot}$)	WFHZ/TAT
^{22}Na......	8.10(−8)	9.68(−8)	0.84
^{26}Al	3.07(−5)	2.92(−5)	1.05
^{44}Ti.......	6.06(−5)	7.40(−5)	0.82
^{56}Ni	8.11(−2)	8.06(−2)	1.01
^{60}Fe	3.35(−6)	5.51(−6)	0.61
^{60}Co	5.63(−6)	2.60(−6)	2.17

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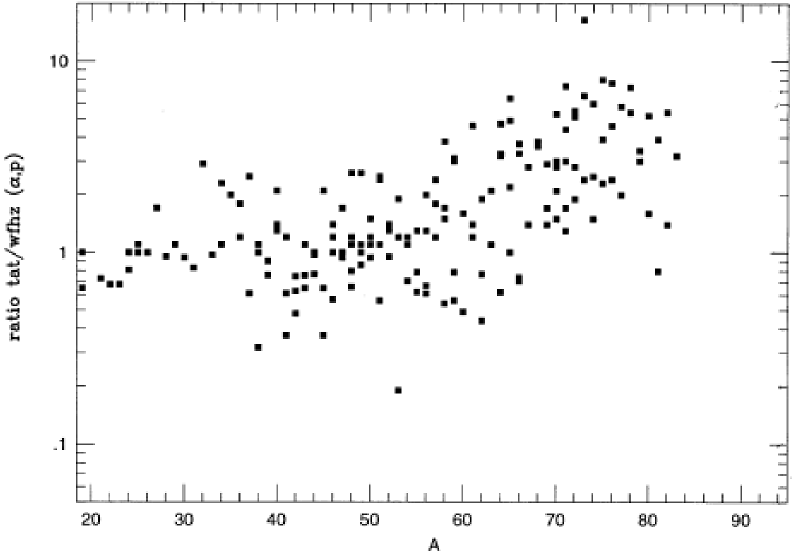
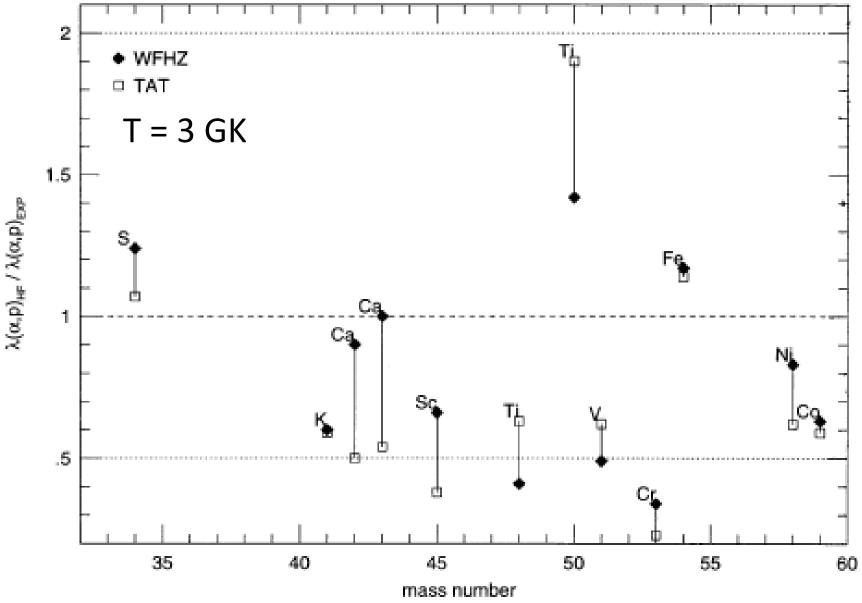


FIG. 9.—Ratios of TAT to WFHZ (α, p) rates evaluated at $T_9 = 2.5$



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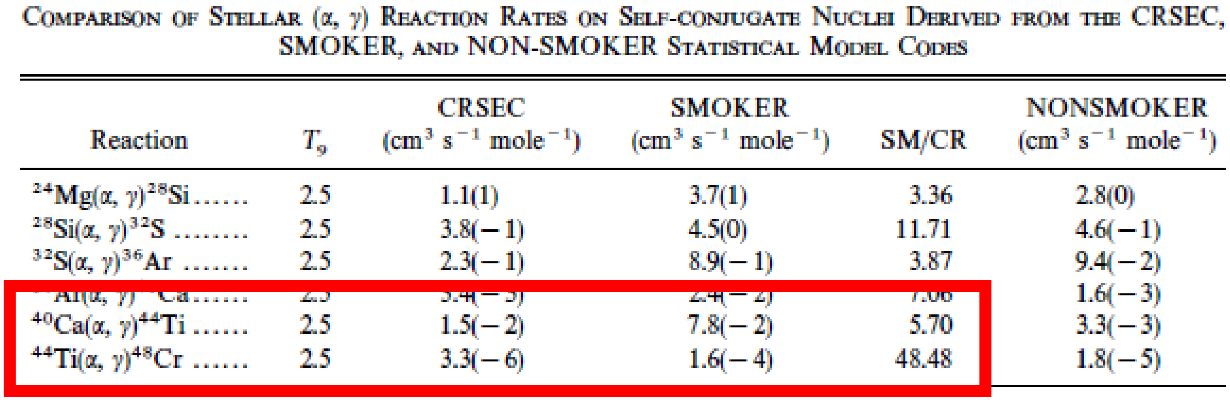
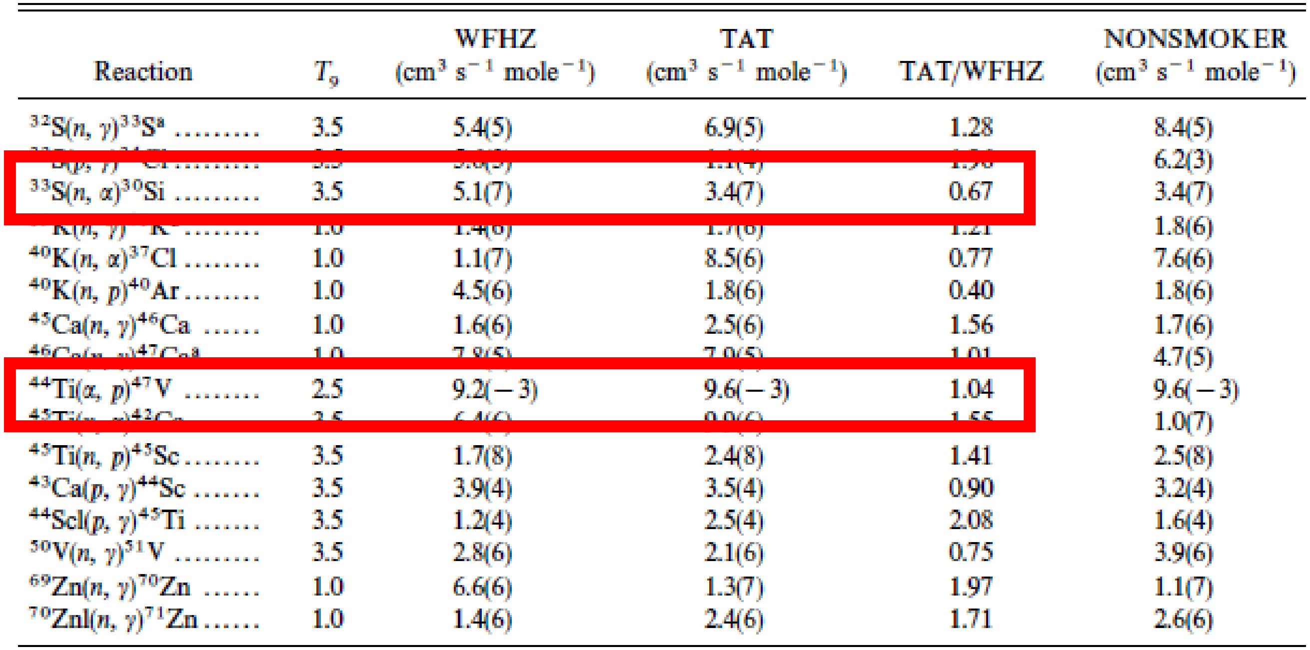


COMPARISON OF STELLAR (α, γ) REACTION RATES ON SELF-CONJUGATE NUCLEI DERIVED FROM THE CRSEC, SMOKER, AND NON-SMOKER STATISTICAL MODEL CODES

Reaction	T_9	CRSEC (cm^3 s^{-1} mole^{-1})	SMOKER (cm^3 s^{-1} mole^{-1})	SM/CR	NONSMOKER (cm^3 s^{-1} mole^{-1})
^{24}Mg(α, γ)^{28}Si......	2.5	1.1(1)	3.7(1)	3.36	2.8(0)
^{28}Si(α, γ)^{32}S	2.5	3.8(−1)	4.5(0)	11.71	4.6(−1)
^{32}S(α, γ)^{36}Ar	2.5	2.3(−1)	8.9(−1)	3.87	9.4(−2)
Ar(α, γ)Ca......	2.5	3.4(−3)	2.4(−2)	7.06	1.6(−3)
^{40}Ca(α, γ)^{44}Ti	2.5	1.5(−2)	7.8(−2)	5.70	3.3(−3)
^{44}Ti(α, γ)^{48}Cr	2.5	3.3(−6)	1.6(−4)	48.48	1.8(−5)



Reaction	T_9	WFHZ (cm^3 s^{-1} mole^{-1})	TAT (cm^3 s^{-1} mole^{-1})	TAT/WFHZ	NONSMOKER (cm^3 s^{-1} mole^{-1})
^{32}S(n, γ)^{33}S^{a}	3.5	5.4(5)	6.9(5)	1.28	8.4(5)
S(p, γ)Cl.........	3.5	[illegible]	1.1(4)	[illegible]	6.2(3)
^{33}S(n, α)^{30}Si	3.5	5.1(7)	3.4(7)	0.67	3.4(7)
K(n, γ)K.........	1.0	1.4(6)	1.7(6)	1.21	1.8(6)
^{40}K(n, α)^{37}Cl	1.0	1.1(7)	8.5(6)	0.77	7.6(6)
^{40}K(n, p)^{40}Ar	1.0	4.5(6)	1.8(6)	0.40	1.8(6)
^{45}Ca(n, γ)^{46}Ca	1.0	1.6(6)	2.5(6)	1.56	1.7(6)
^{46}Ca(n, γ)^{47}Ca^{a}	1.0	7.8(5)	7.9(5)	1.01	4.7(5)
^{44}Ti(α, p)^{47}V	2.5	9.2(−3)	9.6(−3)	1.04	9.6(−3)
^{45}Ti(n, α)^{42}Ca	3.5	6.4(6)	9.9(6)	1.55	1.0(7)
^{45}Ti(n, p)^{45}Sc........	3.5	1.7(8)	2.4(8)	1.41	2.5(8)
^{43}Ca(p, γ)^{44}Sc	3.5	3.9(4)	3.5(4)	0.90	3.2(4)
^{44}Scl(p, γ)^{45}Ti	3.5	1.2(4)	2.5(4)	2.08	1.6(4)
^{50}V(n, γ)^{51}V	3.5	2.8(6)	2.1(6)	0.75	3.9(6)
^{69}Zn(n, γ)^{70}Zn	1.0	6.6(6)	1.3(7)	1.97	1.1(7)
^{70}Znl(n, γ)^{71}Zn......	1.0	1.4(6)	2.4(6)	1.71	2.6(6)

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The et al. 1998

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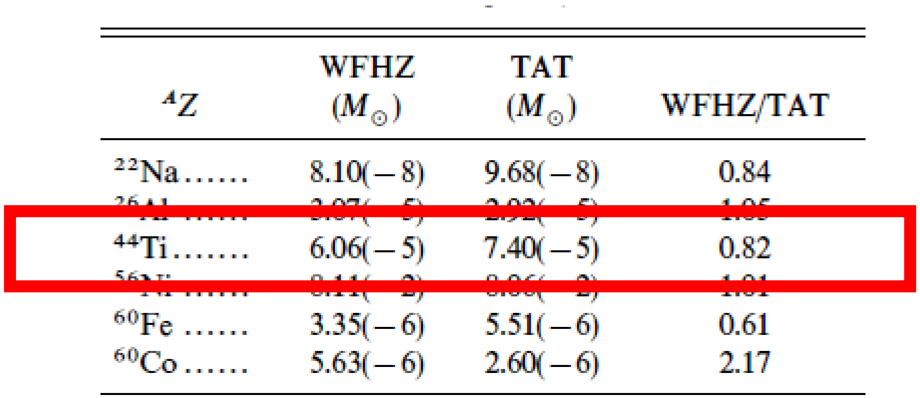

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