Research Day of Universe Cluster: ^{44}Ti

9:30	**From whence doth ye cometh, ^{44}Ti?**	A. Parikh (TUM)
9:40	**Cosmic sources of ^{44}Ti**	R. Diehl (MPE)
9:50	**Gamma-ray lines from ^{44}Ti sources: COMPTEL**	A. Iyudin (MSU, Moscow)
	Gamma-ray lines from ^{44}Ti sources: INTEGRAL	M. Lang (MPE)
10:10	**^{44}Ti abundance ratio to other cosmic abundances**	R. Diehl (MPE)
10:20	**^{44}Ti traces and measurements in meteorites**	P. Hoppe (MPI, Mainz)
10:40	*Discussion: "Observations"*	
11:00	**Coffee break**	
11:30	**Modeling core-collapse supernovae**	A. Marek (MPA)
11:50	**Core collapses and Gamma-Ray Bursts**	P. Mazzali (ESO)
12:10	**The nature of the Cas A Supernova**	J. Vink (SRON, Utrecht)
12:30	**SNIa as ^{44}Ti Sources?**	F. Roepke (MPA)
12:40	*Discussion: "Models"*	
13:00	**Lunch**	
14:00	**Nuclear reaction network calculations**	A. Parikh (TUM)
14:10	**Key nuclear reactions**	S. Bishop (TUM) C. Vockenhuber (ETH, Zurich) G. Rugel (TUM) D. Bemmerer (FZD, Dresden)
14:50	*Discussion: "Nuclear Physics"*	
15:10	**Future Perspectives: the NARF project**	A. Parikh (TUM)
15:20	*Open Discussion Forum*	

^{44}Ti: From whence doth ye cometh?

Anuj Parikh (TUM)

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29														Cu 54 0.023s	Cu 55 0.0354s
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27								Co 46 0.00587s	Co 47 0.0143s	Co 48 0.0132s	Co 49 0.0261s	Co 50 0.044s	Co 51 0.0533s	Co 52 0.115s	Co 53 0.247s
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25							Mn 43 0.0103s	Mn 44 0.0143s	Mn 45 0.0367s	Mn 46 0.034s	Mn 47 0.1s	Mn 48 0.1581s	Mn 49 0.3821s	Mn 50 1.75m	Mn 51 46.2m
24					Cr 40 0.00543s	Cr 41 0.0107s	Cr 42 0.0134s	Cr 43 0.0216s	Cr 44 0.053s	Cr 45 0.05s	Cr 46 0.26s	Cr 47 0.5s	Cr 48 21.56h	Cr 49 42.3m	Cr 50 4.345
23					V 39 0.0092s	V 40 0.0195s	V 41 0.0304s	V 42 0.0456s	V 43 0.141s	V 44 0.15s	V 45 0.547s	V 46 [illegible].4226s	V 47 32.6m	V 48 15.97d	V 49 330d
22				Ti 37 0.00744s	Ti 38 0.0196s	Ti 39 0.031s	Ti 40 0.0534s	Ti 41 0.08s	Ti 42 0.199s	Ti 43 0.509s	Ti 44 60y	Ti 45 [illegible].08h	Ti 46 8.25	Ti 47 7.44	Ti 48 73.72
21				Sc 36 0.0162s	Sc 37 0.0294s	Sc 38 0.0522s	Sc 39 0.0921s	Sc 40 0.1823s	Sc 41 0.5963s	Sc 42 1.028m	Sc 43 [illegible]	Sc 44 2.442d	Sc 45 100	Sc 46 83.79d	Sc 47 3.349d
20			Ca 34 0.0172s	Ca 35 0.0257s	Ca 36 0.102s	Ca 37 0.1811s	Ca 38 0.44s	Ca 39 0.8596s	Ca 40 96.941	Ca 41 1.03e+05y	Ca 42 0.647	Ca 43 0.135	Ca 44 2.086	Ca 45 162.6d	Ca 46 0.004
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18	Ar 30 0.013s	Ar 31 0.0141s	Ar 32 0.098s	Ar 33 0.173s	Ar 34 0.8445s	Ar 35 1.775s	Ar 36 0.3365	Ar 37 34.95d	Ar 38 0.0632	Ar 39 269y	Ar 40 99.6003	Ar 41 1.822h	Ar 42 32.9y	Ar 43 5.37m	Ar 44 11.87m
17	Cl 29 0.0316s	Cl 30 0.0474s	Cl 31 0.15s	Cl 32 0.298s	Cl 33 2.511s	Cl 34 32m	Cl 35 75.78	Cl 36 3.01e+05y	Cl 37 24.22	Cl 38 37.24m	Cl 39 55.6m	Cl 40 1.35m	Cl 41 38.4s	Cl 42 6.8s	Cl 43 3.3s
16	S 28 0.125s	S 29 0.187s	S 30 1.178s	S 31 2.572s	S 32 94.93	S 33 0.76	S 34 4.29	S 35 87.51d	S 36 0.02	S 37 5.05m	S 38 2.838h	S 39 11.5s	S 40 8.8s	S 41 2.6s	S 42 0.56s
15	P 27 0.26s	P 28 0.2703s	P 29 4.14s	P 30 2.498m	P 31 100	P 32 14.26d	P 33 25.34d	P 34 12.43s	P 35 47.3s	P 36 5.6s	P 37 2.31s	P 38 0.64s	P 39 0.25s	P 40 0.125s	P 41 0.1s

^{44}Ti: From whence doth ye cometh?

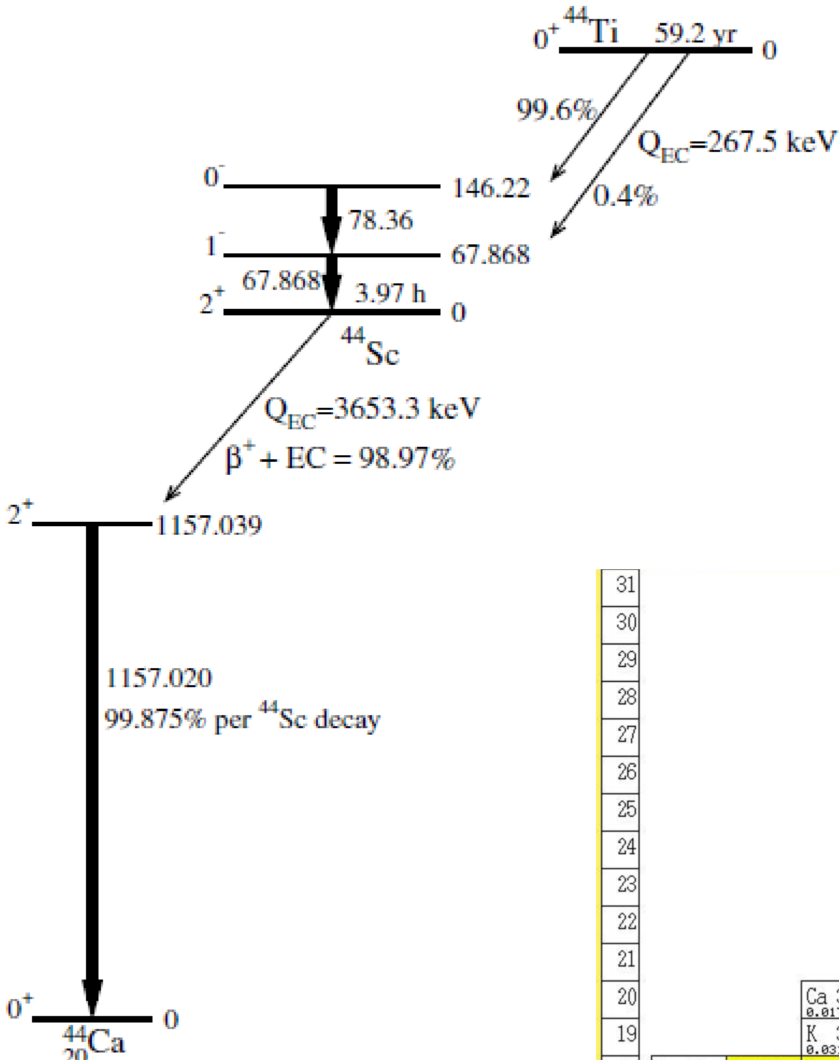


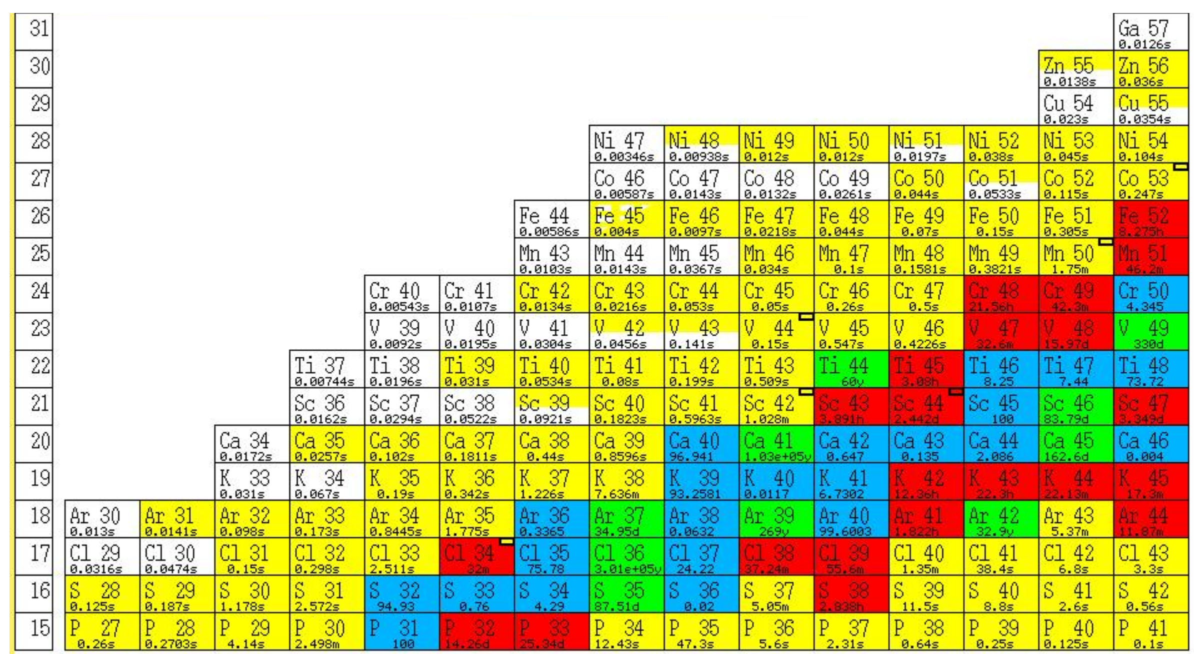
TABLE I. Summary of previous measurements of ^{44}Ti half-life.

Half-life (years)[a]	Method used for the measurement[b]	Reference
46.4±1.7	Specific activity (MS + γ activity)	[15]
48.2±0.9	Specific activity (MS + γ activity)	[16]
54.2±2.1	Specific activity (AMS + γ activity)	[17]
66.6±1.6	Decay (β activity)	[18]
63±3	Decay (γ activity)	[19]
59.0±0.6	Decay (γ activity relative to ^{60}Co)	[8]
60.3±1.3	Specific activity (HISP + γ activity)	[20]
62±2	Decay (γ activity relative to ^{22}Na)	[21]
60.7±1.2	Decay (γ activity)	[22]
59±2	Specific activity (HISP + γ activity)	[23]

[a] 1σ uncertainties are given except for Ref. [18], where the authors report 2σ uncertainty.

[b] Abbreviations: MS = mass spectrometry; AMS = accelerator mass spectrometry; HISP = heavy-ion spallation reaction with on-line counting of ^{44}Ti ions.

Ahmad et al. (2006): 58.9 ± 0.3 y



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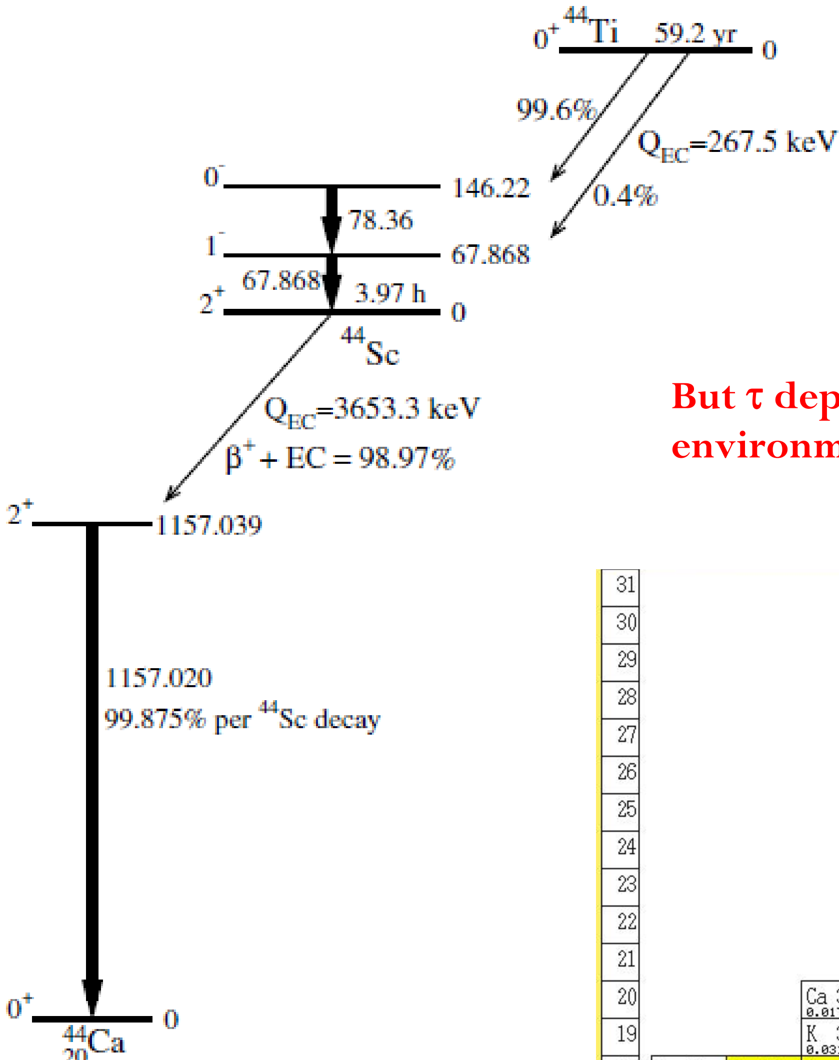

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But τ depends on environment…

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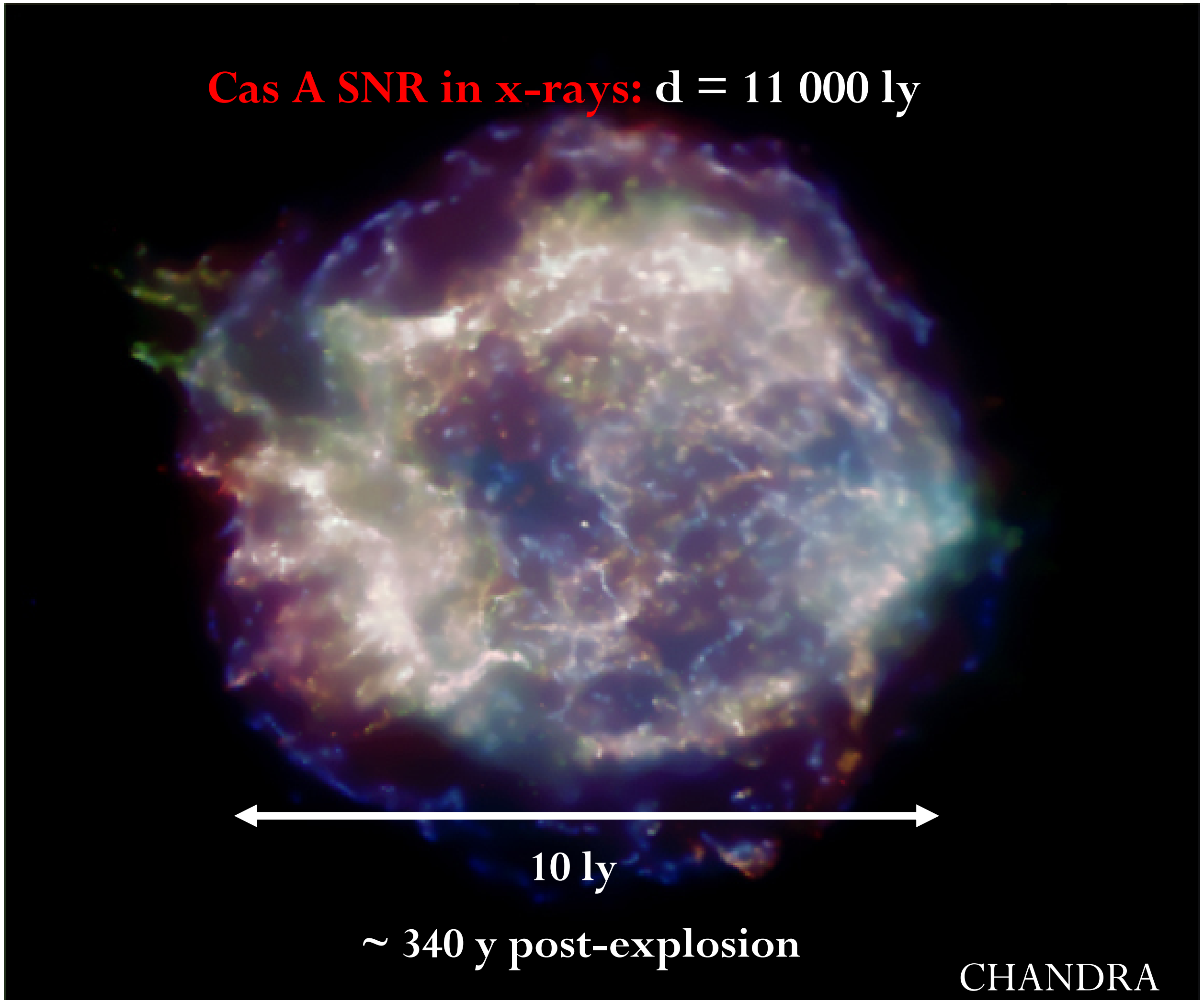
^{44}Ti: From whence doth ye cometh?

Woosley, Arnett and Clayton (1973): Explosive Si burning in ccSN → alpha-rich freeze-out

(Shock-heated single zone, followed by adiabatic expansion)



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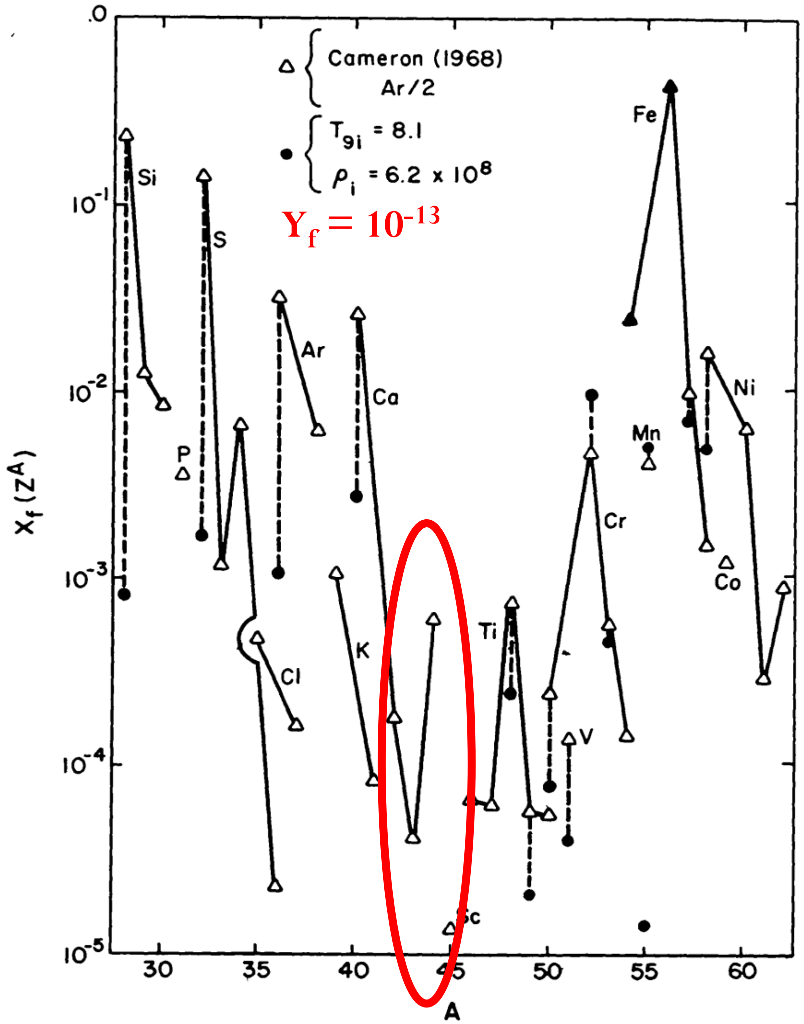

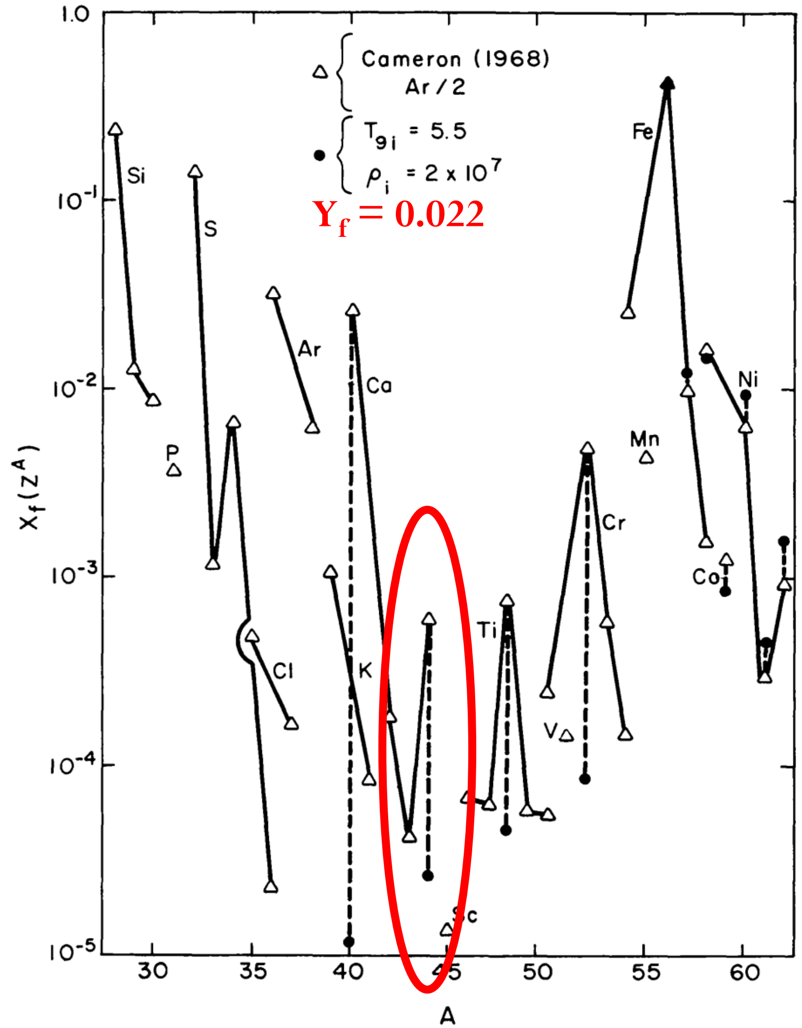

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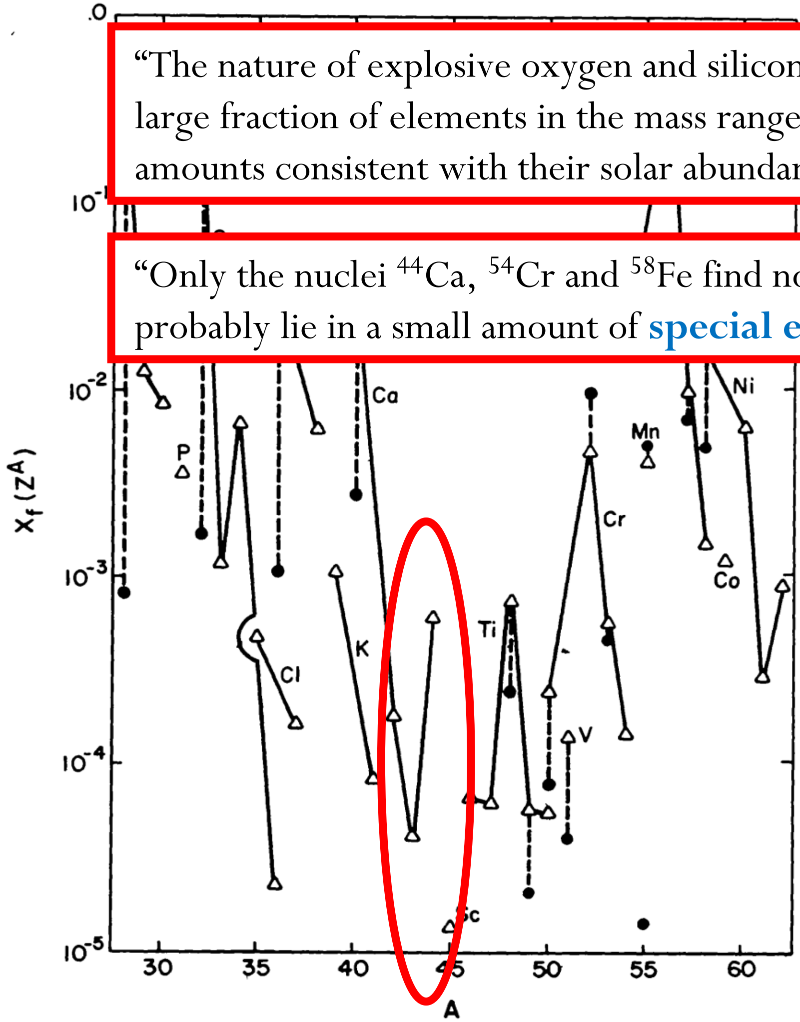

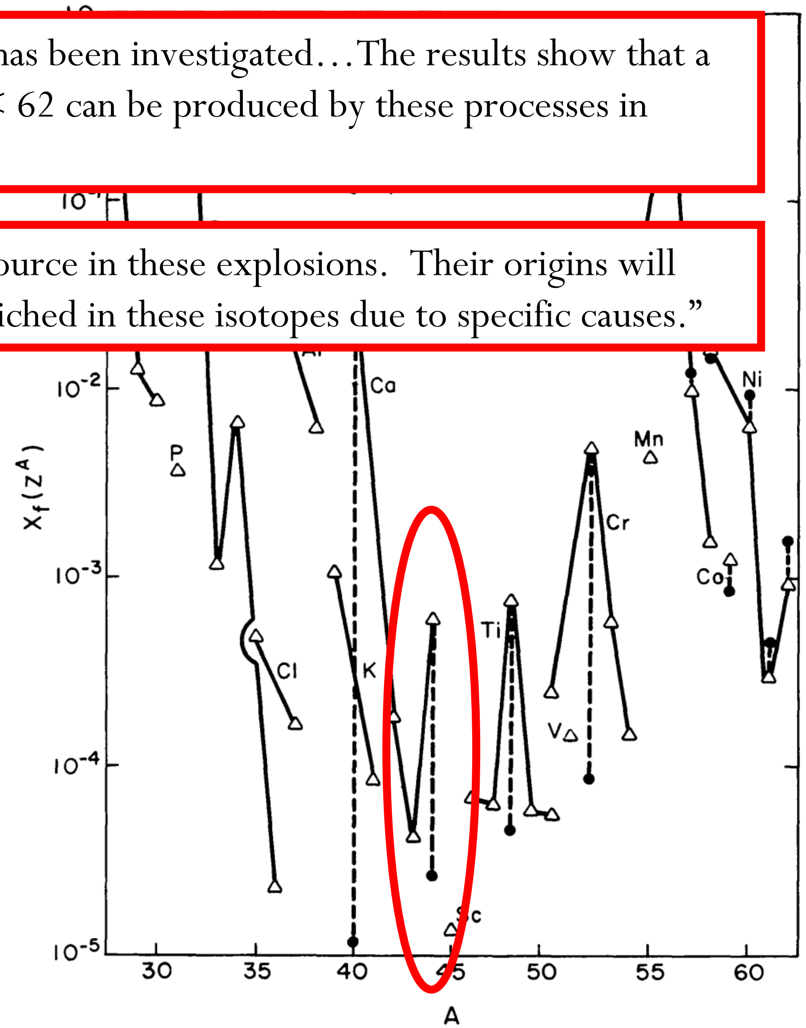

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Woosley and Hoffman (1991): "The presence of substantial ^{44}Ti is an indicator of a strong alpha-rich freeze-out. There is no other place it can be made."

	predicted ^{44}Ti / event	*frequency*
ccSN (Woo95, Thi96, Rau02, Lim03)	$<10^{-4}$ M_{sol}	~3/100y
Type Ia SN (Iwa99, Tra04, Roe05)	$\sim10^{-6} - 10^{-5}$ M_{sol}	~0.3/100y
He-detonated, sub-Chand. TN SN (Woo94, Liv95)	$\sim10^{-3} - 10^{-2}$ M_{sol}	rare…

In ccSN: ^{44}Ti would be in the deepest layers of the ejecta → mass cut, ^{44}Ti / ^{56}Fe

^{44}Ti helps power the late lightcurve (> 1500 d, supplanting ^{56}Co (77 d), ^{57}Co (272 d))

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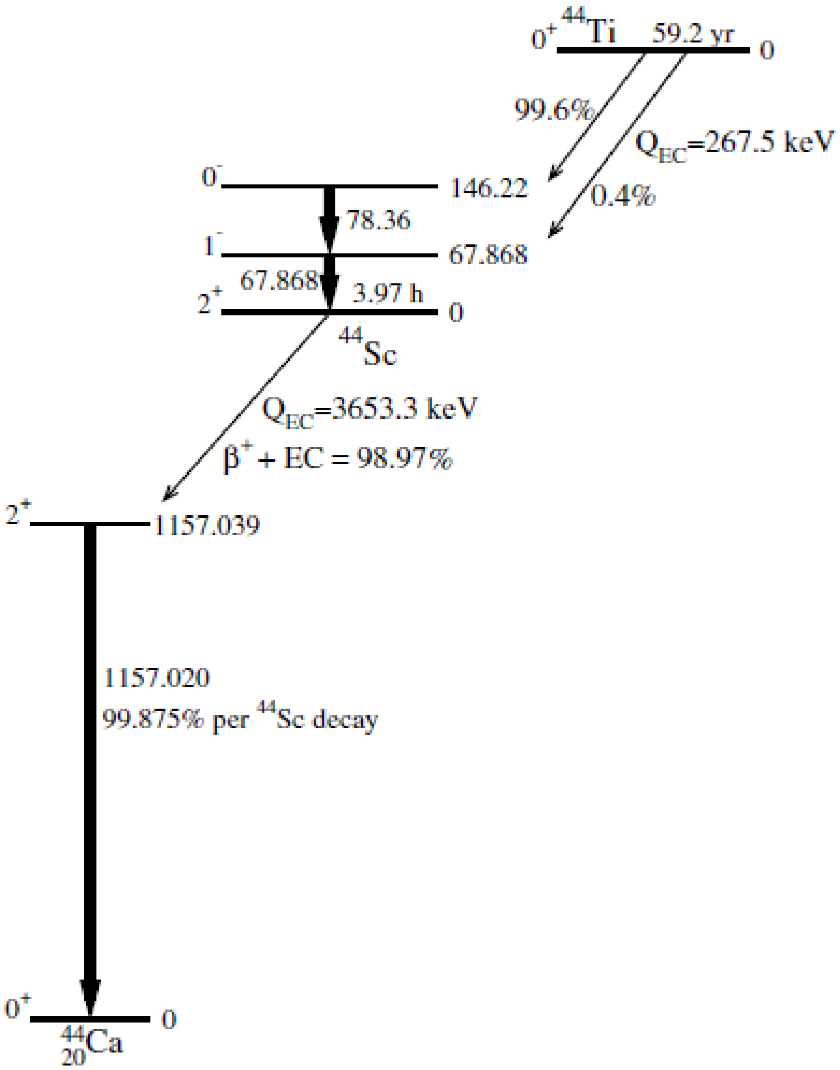

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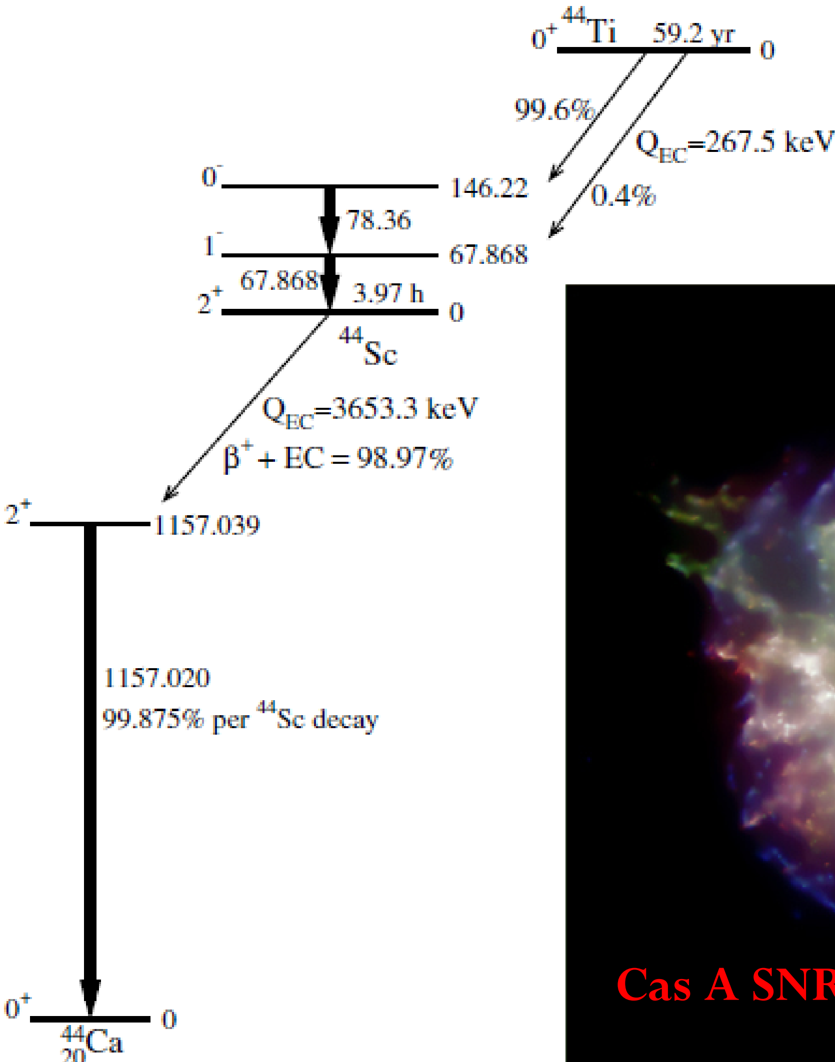
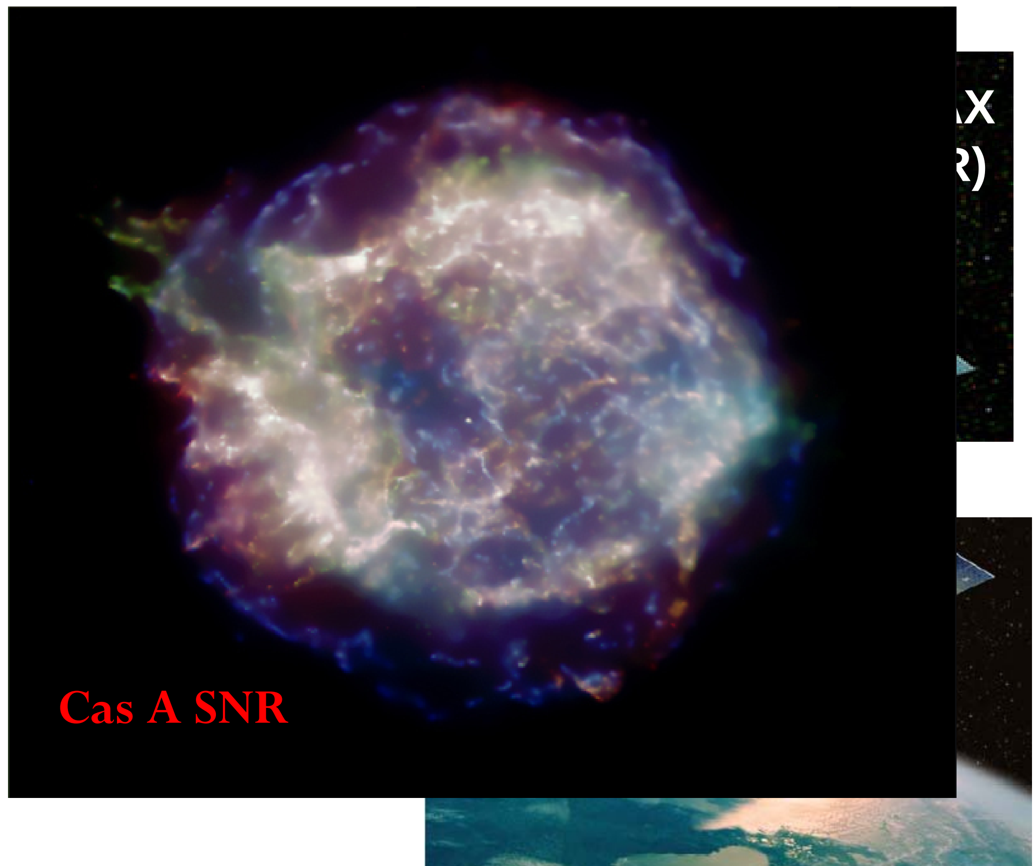
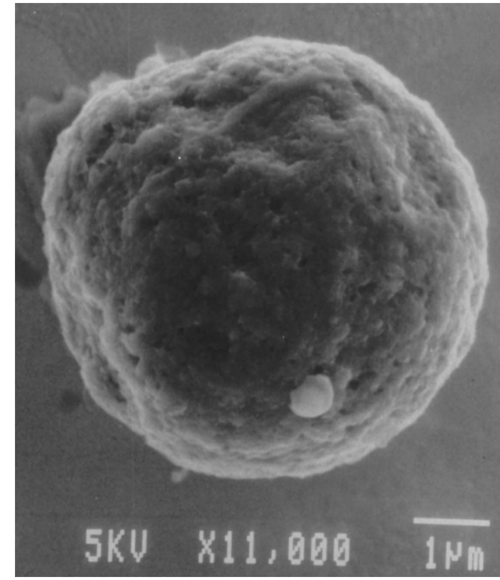




^{44}Ti: From whence doth ye cometh?

Murchison: 1969, Australia, > 100 kg



SiC X grains show isotopic ratios distinct from 'mainstream' SiC grains, including **high ^{44}Ca/^{40}Ca ratios** relative to solar (as large as 138x [Nit96]).

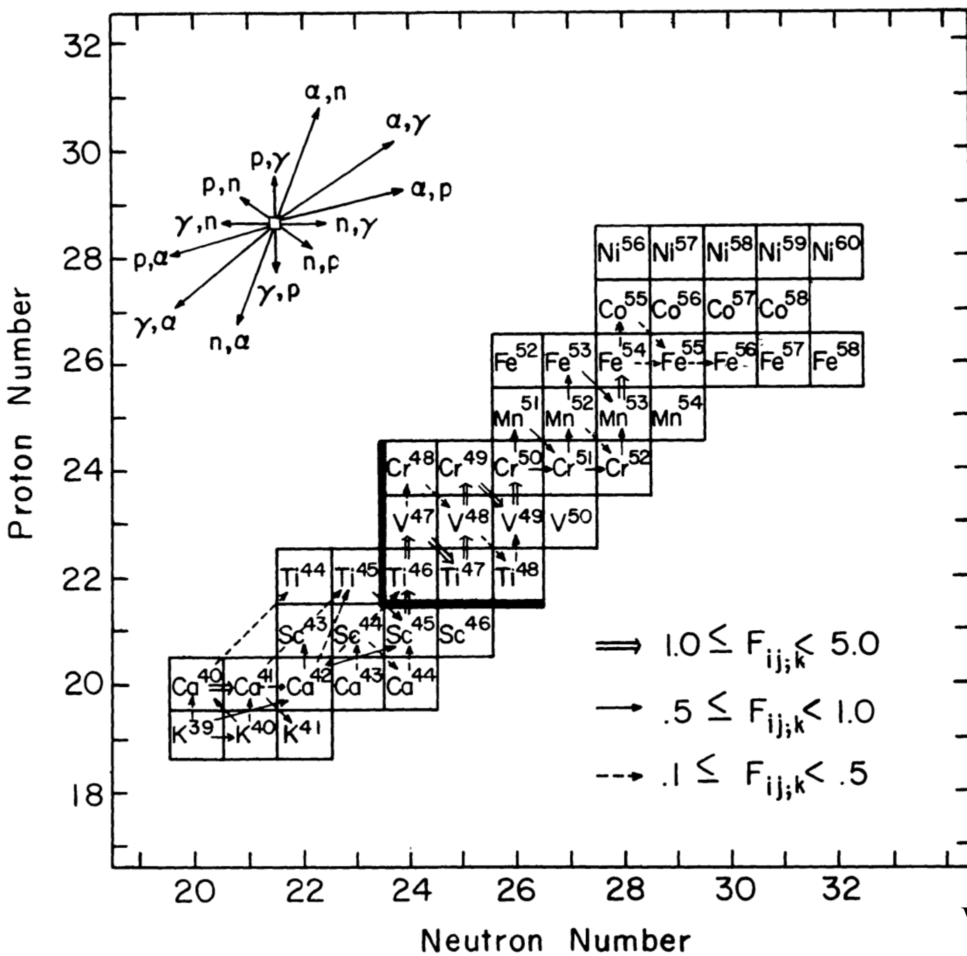
SN origin? Grains sample different production events, different portions of SN interior…

Need relative direct production of ^{44}Ti and ^{44}Ca in SNe (1:1? [Tim96])
→ also important for ^{44}Ca solar constraint → GCE → current ^{44}Ti production rate

^{44}Ti: From whence doth ye cometh?

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

- single zone with T_i = 5.5 GK, ρ_i = 10^7 g/cm^3 → adiabatic expansion
- same conditions as Woosley and Hoffman (1991) (i.e. Si burning → alpha-rich freeze-out)
- post-processing sensitivity study



Woosley et al. 1973

^{44}Ti: From whence doth ye cometh?

The et al. 2006: "Are ^{44}Ti producing Supernovae Exceptional?"

Based on: ^{44}Ti ejection in ccSN ~ 10^{-4} M_{sol} (~CasA)

experimental rate measurements

Galactic ccSN rate ~ 3 / 100 y

$t_{1/2}$ (^{44}Ti) = 59 y

current detection limits (down to 10^{-5} ph/cm^2/s)

Expect: ~ several currently detectable ^{44}Ti **γ-ray** sources

Observed: only **one** clear source (Cas A) *far from the inner Galaxy*!

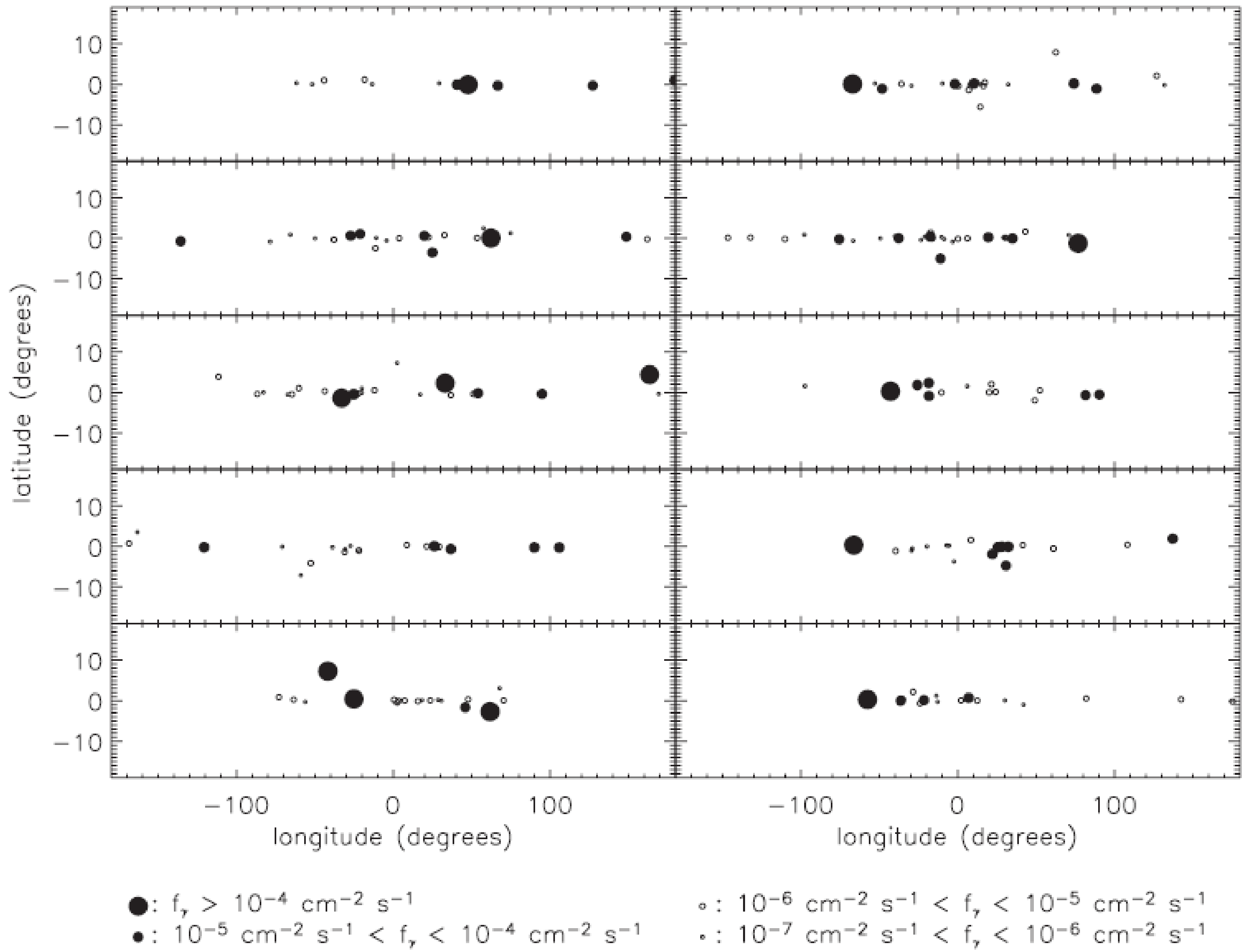


Fig. 2. The expected Ti sky of 10 simulated galaxies of model **A** where the supernova recurrence time is taken to be 30 years and the supernovae ratio of Ia:Ib:II = 0.10:0.15:0.75. Simulating a 10^5 galaxy sky, a gamma-ray detector with a detection limit of 10^{-5} cm^{-2} s^{-1} would have a probability of detecting 0, 1, and 2 ^{44}Ti sources of 0.0017, 0.012, and 0.037, respectively. A slightly better instrument than the 10^{-5} cm^{-2} s^{-1} detection limit would detect several ^{44}Ti sources.