

RIKEN Scientific Educational Video

# “Element Genesis -Solving the Mystery”

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- German, Italian, Hungarian, Korean translations are undergoing.
- NuPECC's use for PANS (Public Awareness of Nuclear Science) Project
- Creative Excellence Award at U.S. Int. Film Festival (2003)
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Y.MOTIZUKI, Workshop on Astronomy  
with Radioactivities VII, 5/27/03

**$^{44}\text{Ti}$  Radioactivity  
in Young SNRs:  
Cas A and SN 1987A**

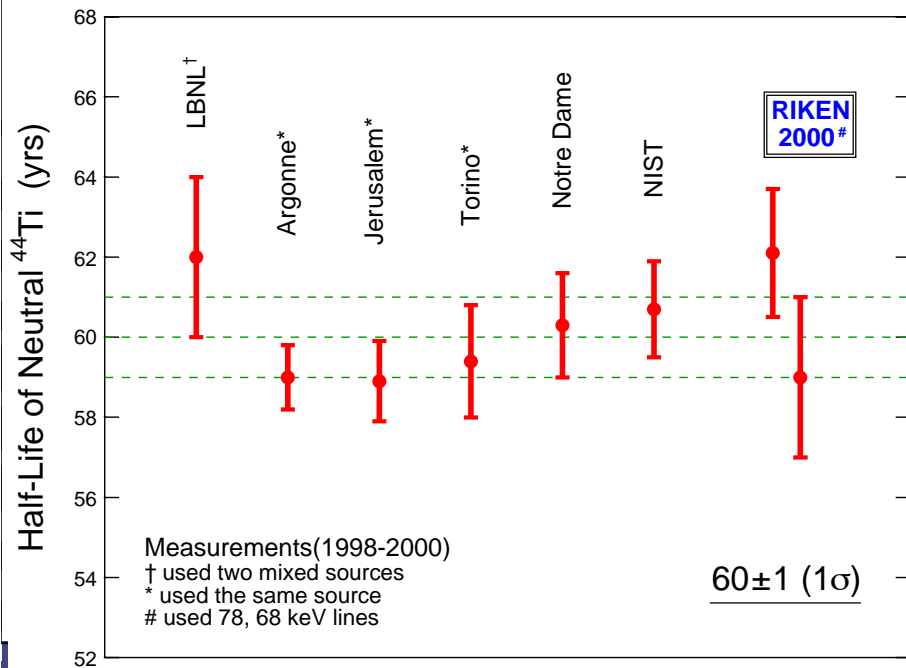
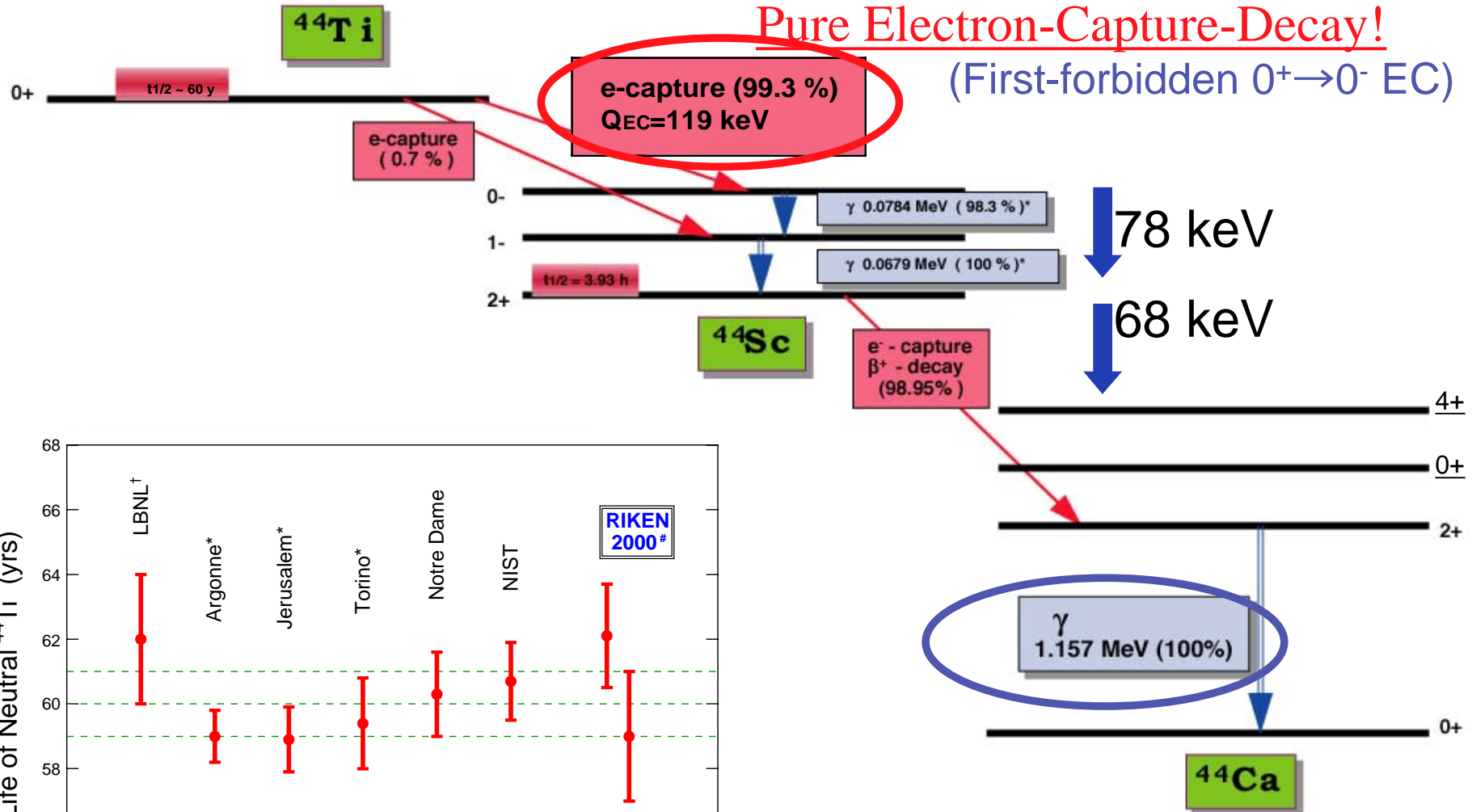
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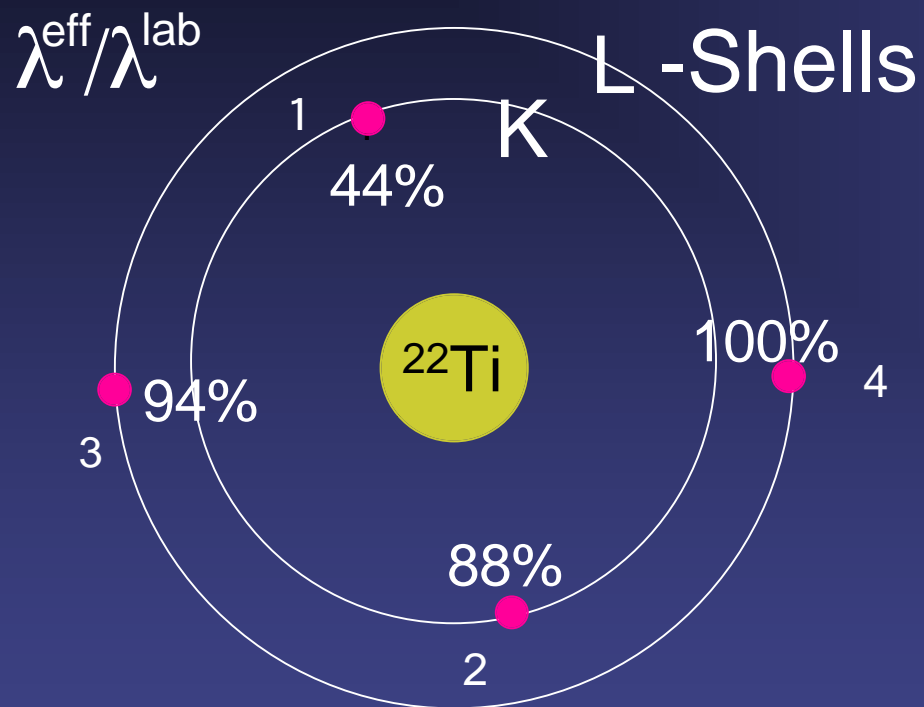
Workshop on Astronomy with Radioactivities IV  
and MeV Gamma-Ray, Kloster Seeon, Germany

5/27/03

# $^{44}\text{Ti}$ Decay



# Decay rate of highly ionized $^{44}\text{Ti}$



## Atomic Electron Binding Energies

K electrons ( $1S_{1/2}$ ) ..... 6.6 keV

$L_I$  electrons ( $2S_{1/2}$ ) ..... 1.6 keV

$L_{II}$  electrons ( $2P_{1/2}$ ) ..... 1.6 keV

$L_{III}$  electrons ( $2P_{3/2}$ ) ..... 1.6 keV

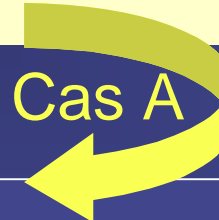
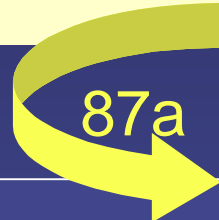
\*Theoretically calculated for non-relativistic electrons & point-charge nucleus (simple estimate)

# Activity Change by Ionization: Linear Analysis

$$A = N_0 \lambda e^{-\lambda t}$$

Always Negative

$$\frac{\Delta A}{A} = (1 - \lambda t) \frac{\Delta \lambda}{\lambda}$$



$^{44}\text{Ti}$	$\text{Ti}^{21+}$	$\text{Ti}^{20+}$
$\Delta A/A$	-0.46	-0.1
	~50%	10%
	Reduction!	

$^{44}\text{Ti}$	$\text{Ti}^{21+}$	$\text{Ti}^{20+}$
$\Delta A/A$	+1.5	+0.32
	factor 2.5	30%
	Enhance!	

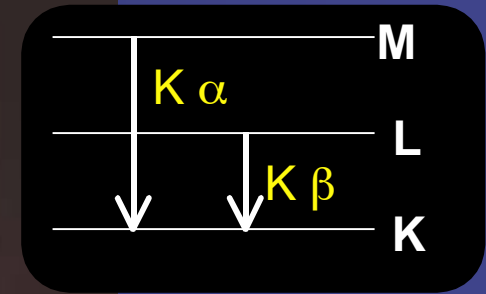
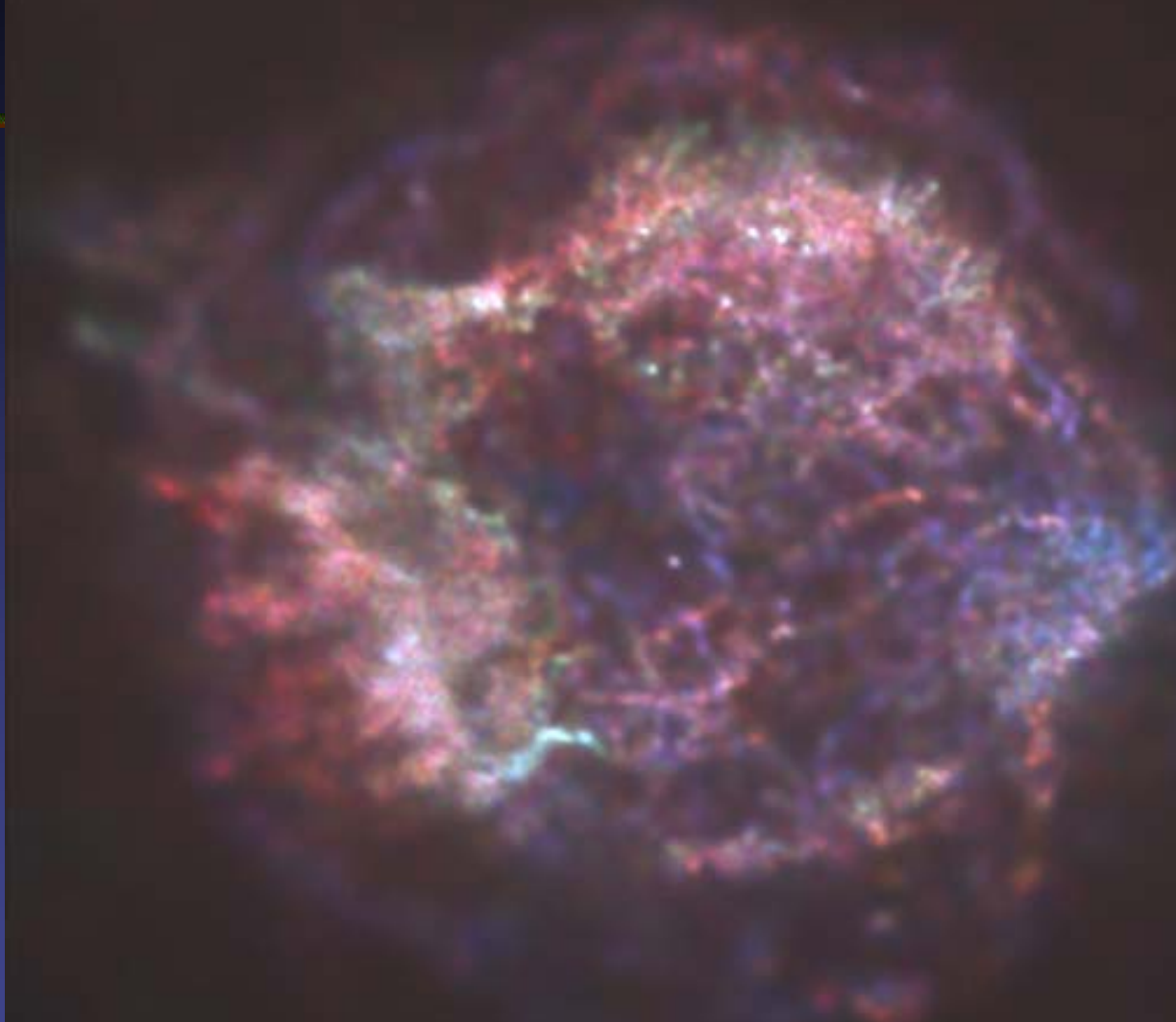
# Element map of Cas A

(Chandra X-ray Obs.)

Red: K shell lines of O, Ne, Mg

Green: K shell lines of Si

Blue: K shell lines of Fe, Ca, Ar, S

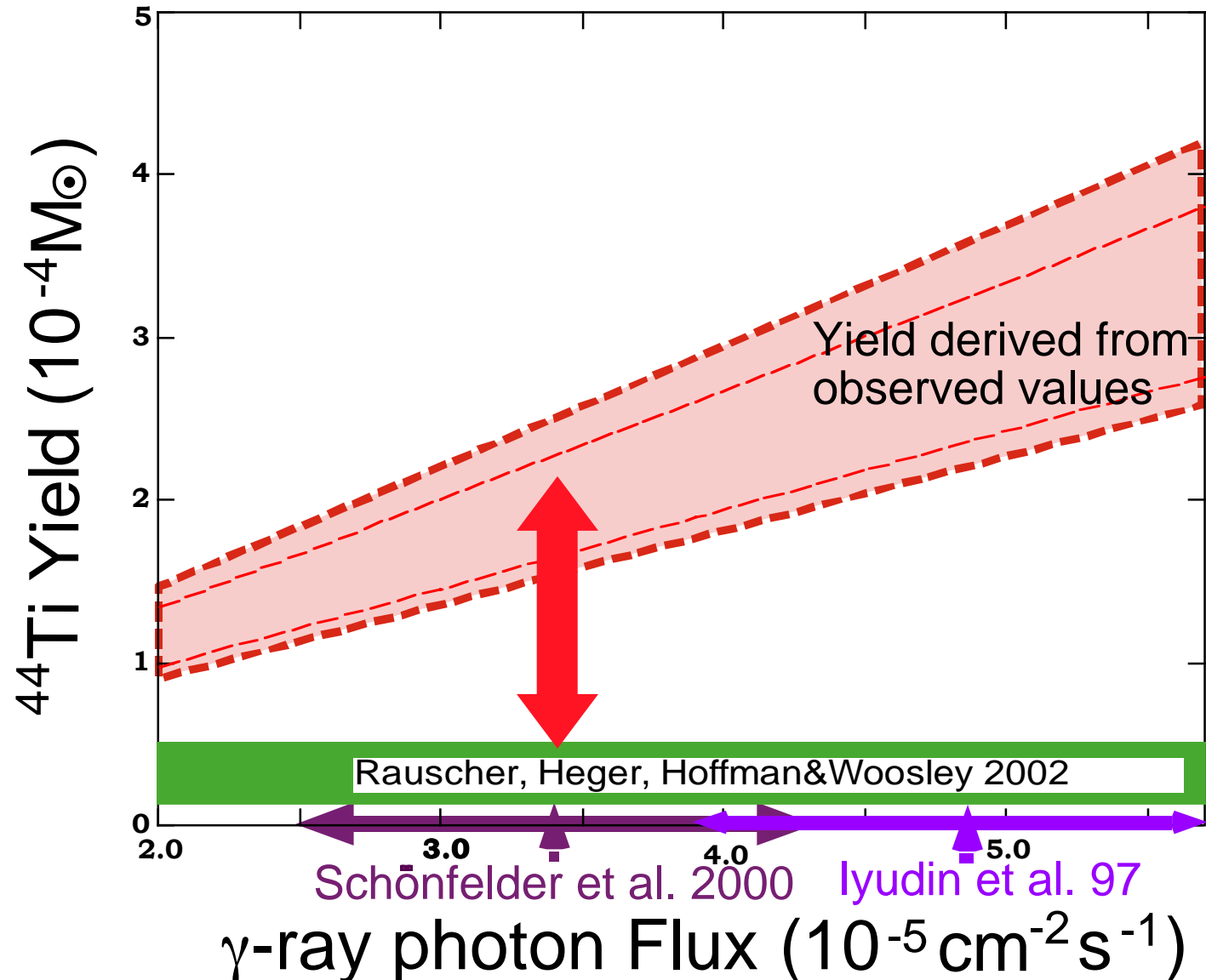


Age  $\sim 320$  y

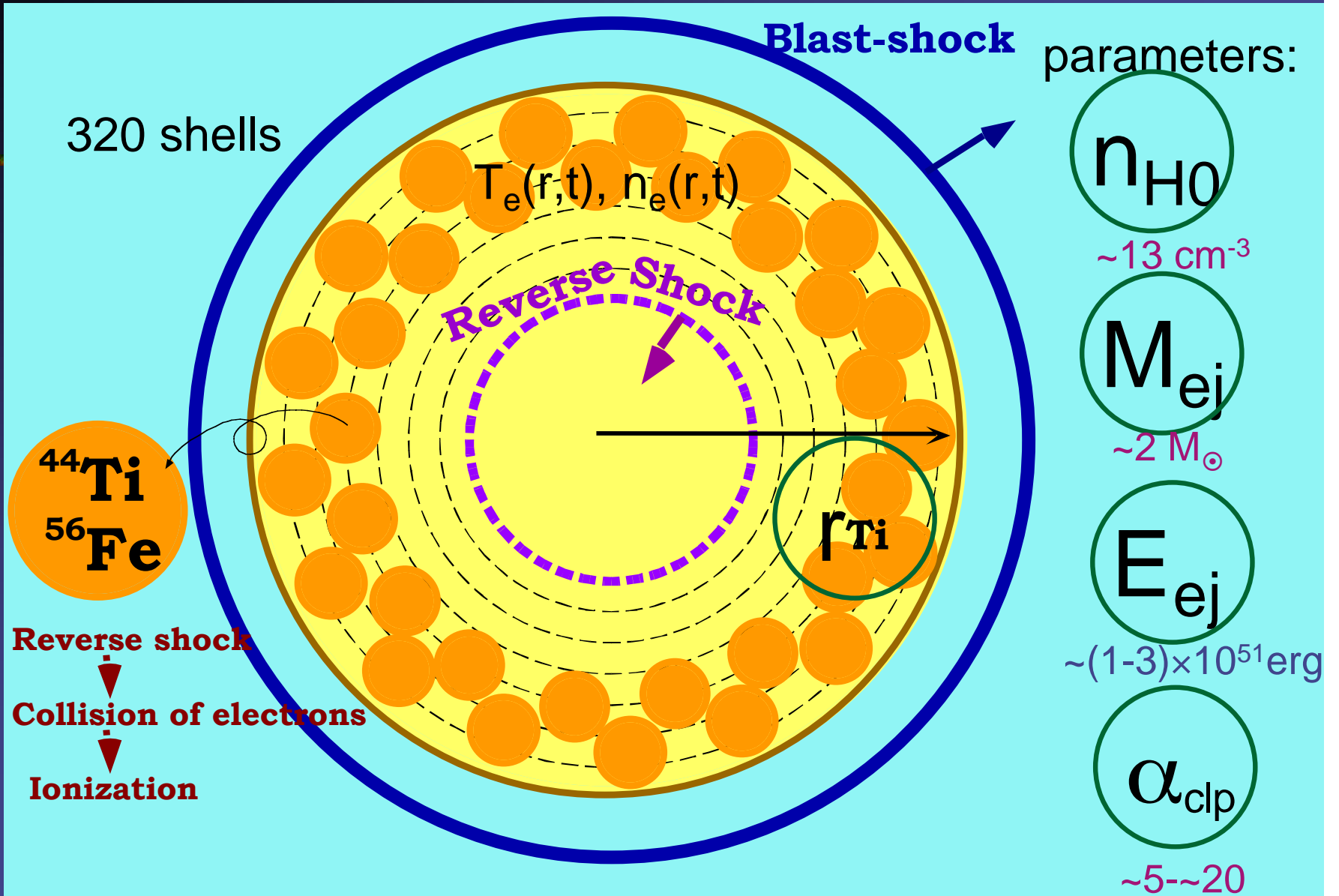
$d \sim 3.4^{+0.3}_{-0.1}$  kpc

$t_{1/2} = 60 \pm 3$  yrs ( $3\sigma$ )

# Discrepancy between theory and observation



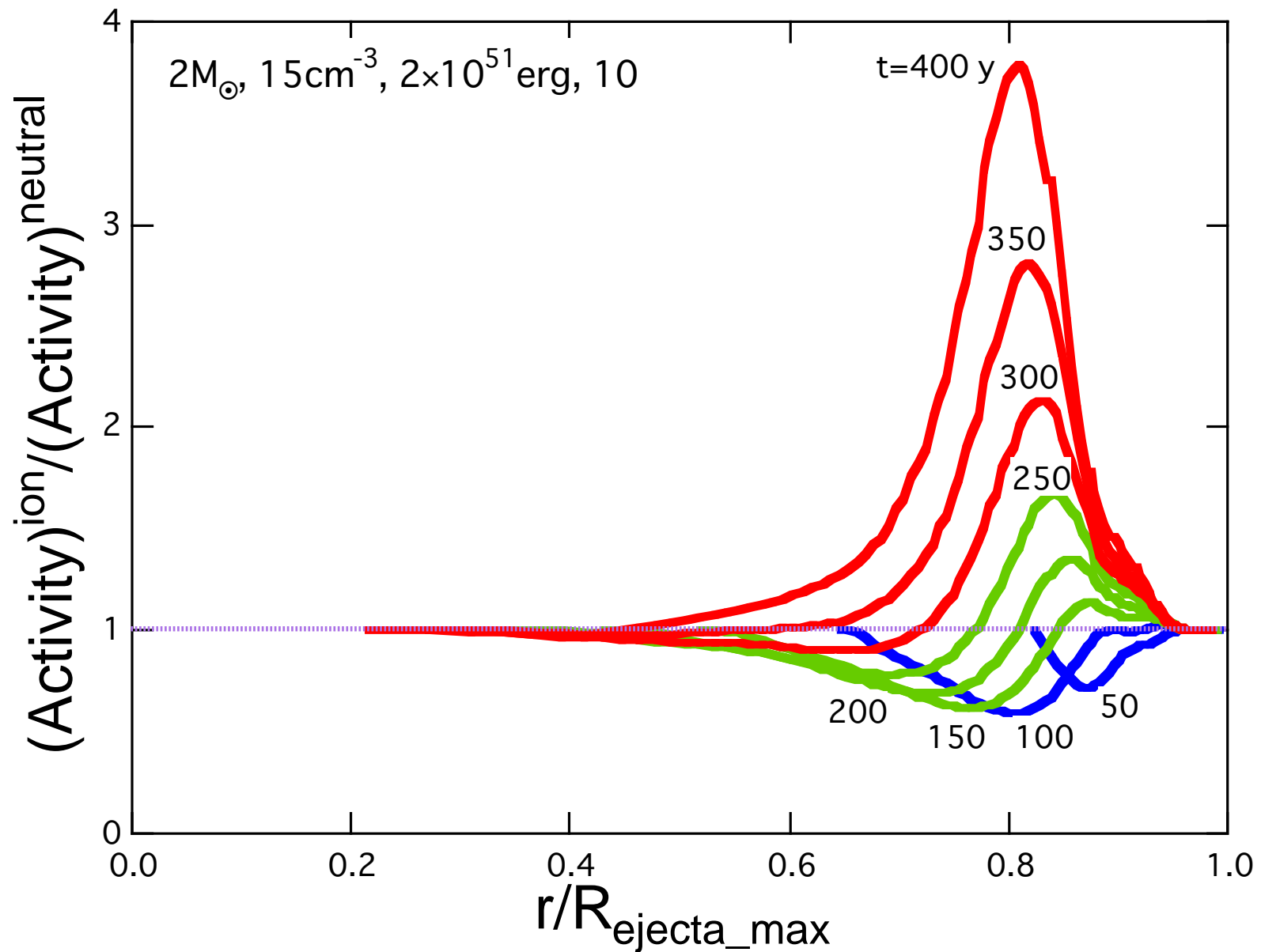
SNR Model: McKee & Truelove 95+Clumpy Structure+recent X-ray obs.  
 Updated from: Y.M. 01; Y.M., Takahashi, Janka, Hillebrandt & Diehl 99



# Microphysics

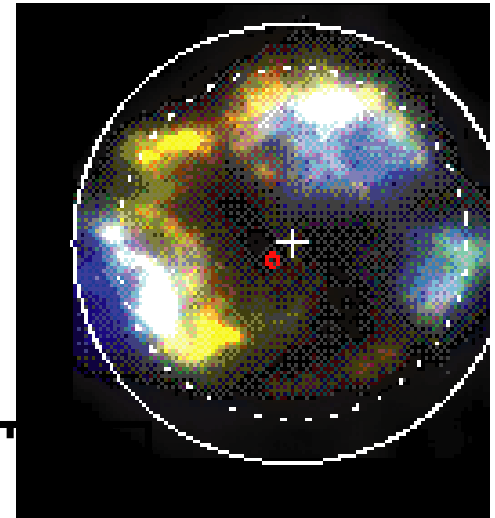
- **Electron capture decay**
- **Ionization, Recombination**
- **non-thermal equilibrium  $T_e \neq T_i$**
- **No collisional (**ionization**) equilibrium**
- **shocked clump temperature**
- **non-adiabatic effects**  
**by ionization / recombination**

# Activity Evolution with Ionization

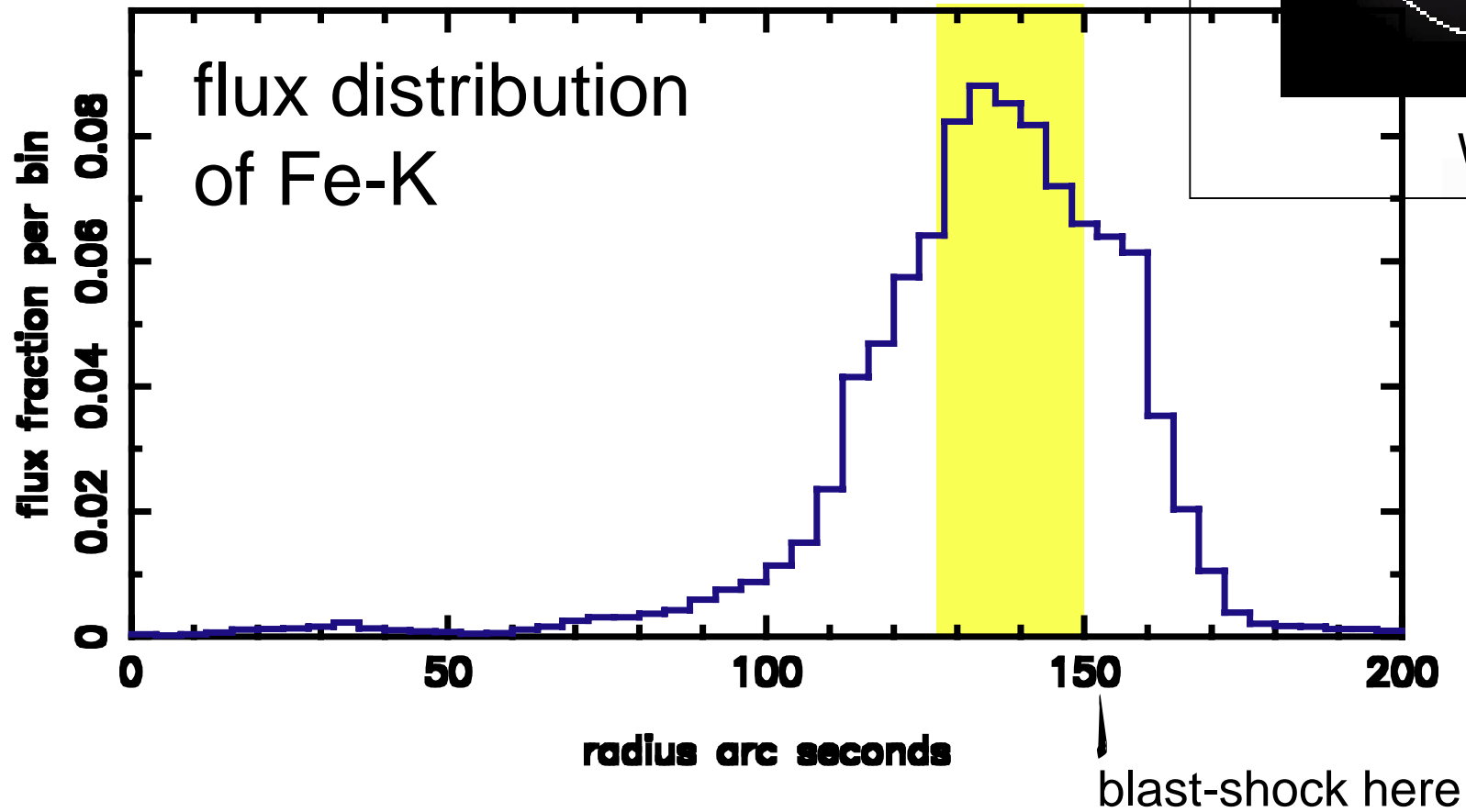


# Chandra X-ray Observation of Cas A, Willingale et al. 2002

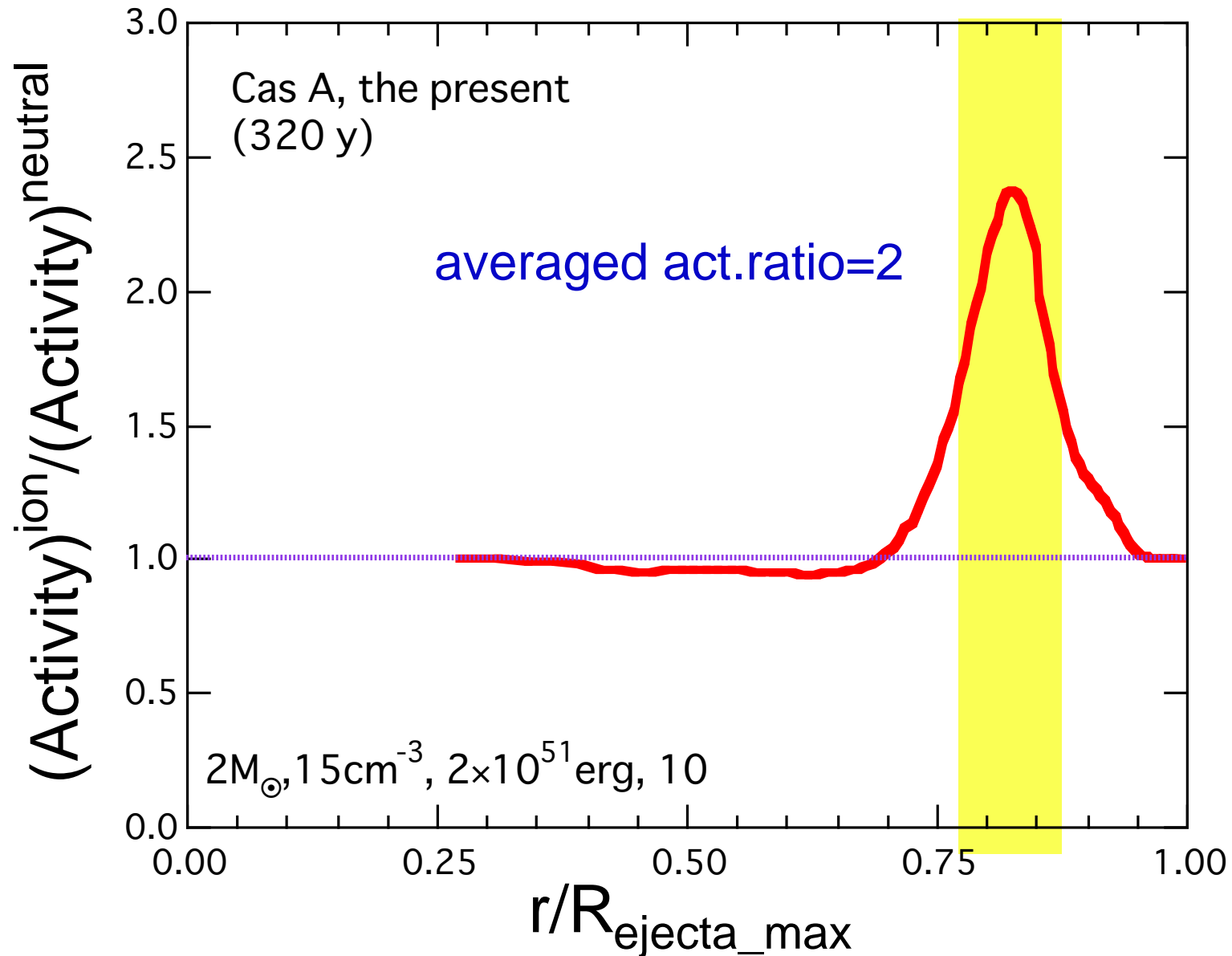
North -->



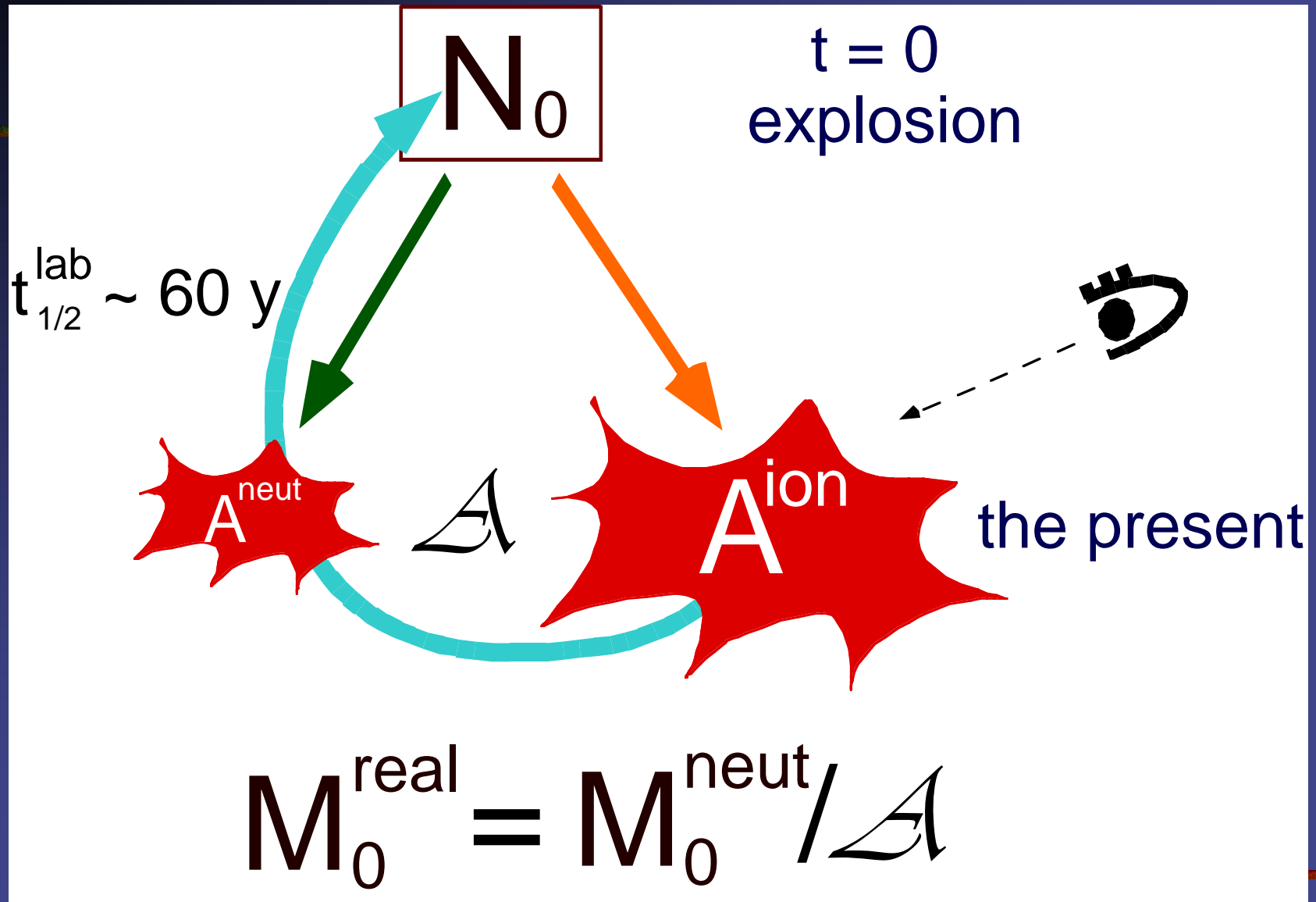
West -->



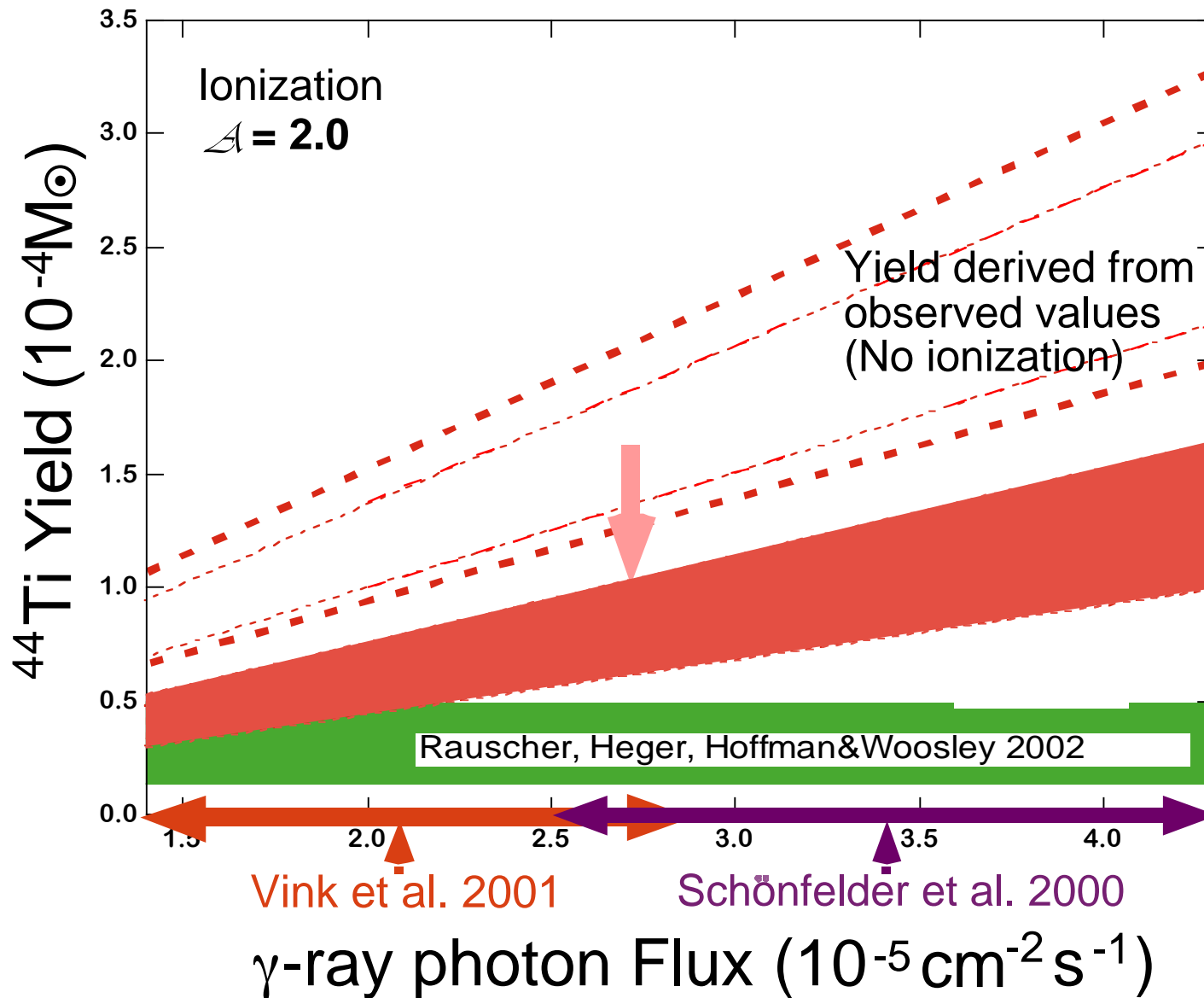
# The Present $^{44}\text{Ti}$ Activity in Cas A



# Real Initial Mass



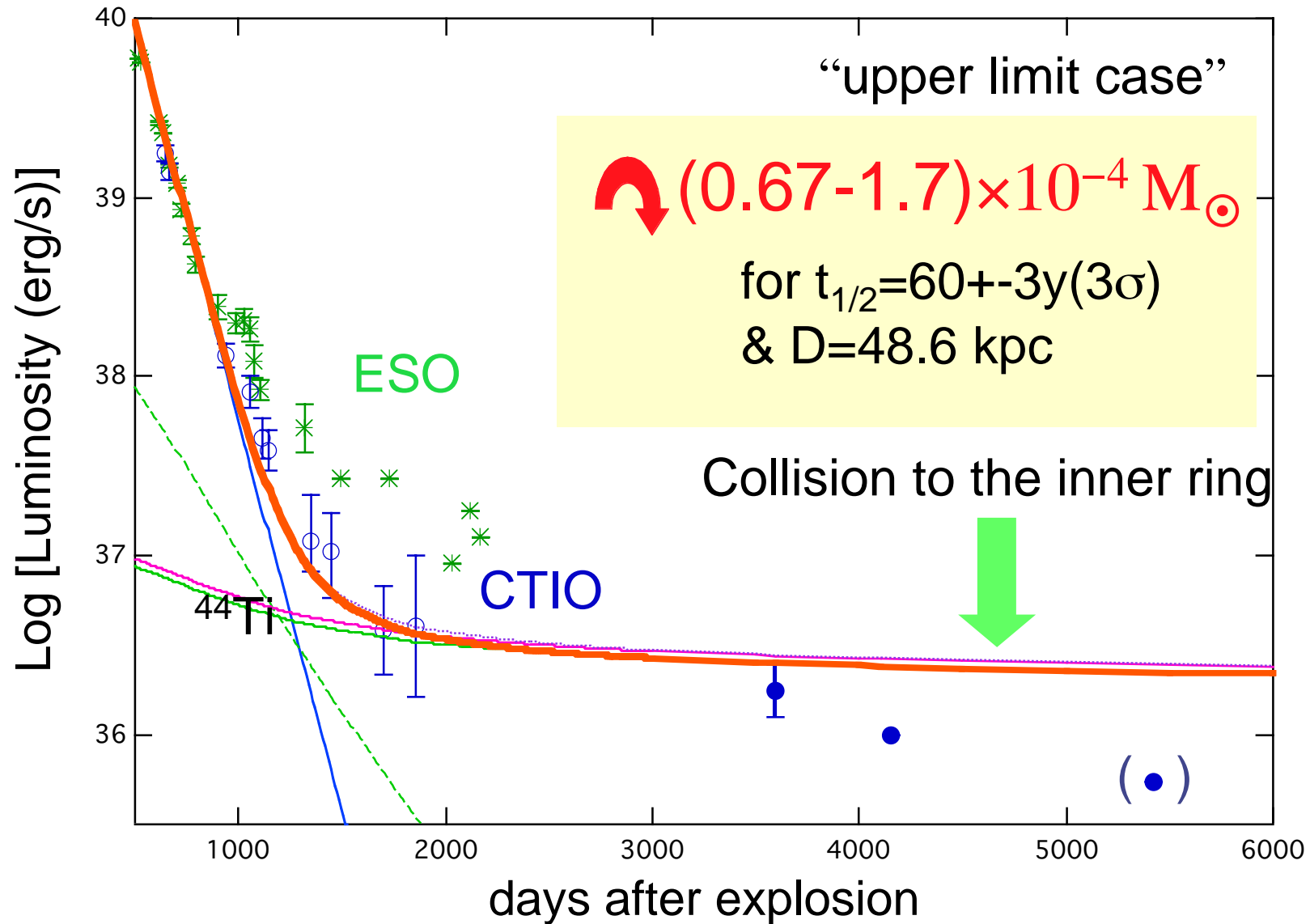
# Coincidence between theory and observation?



# Summary : $^{44}\text{Ti}$ in Cas A

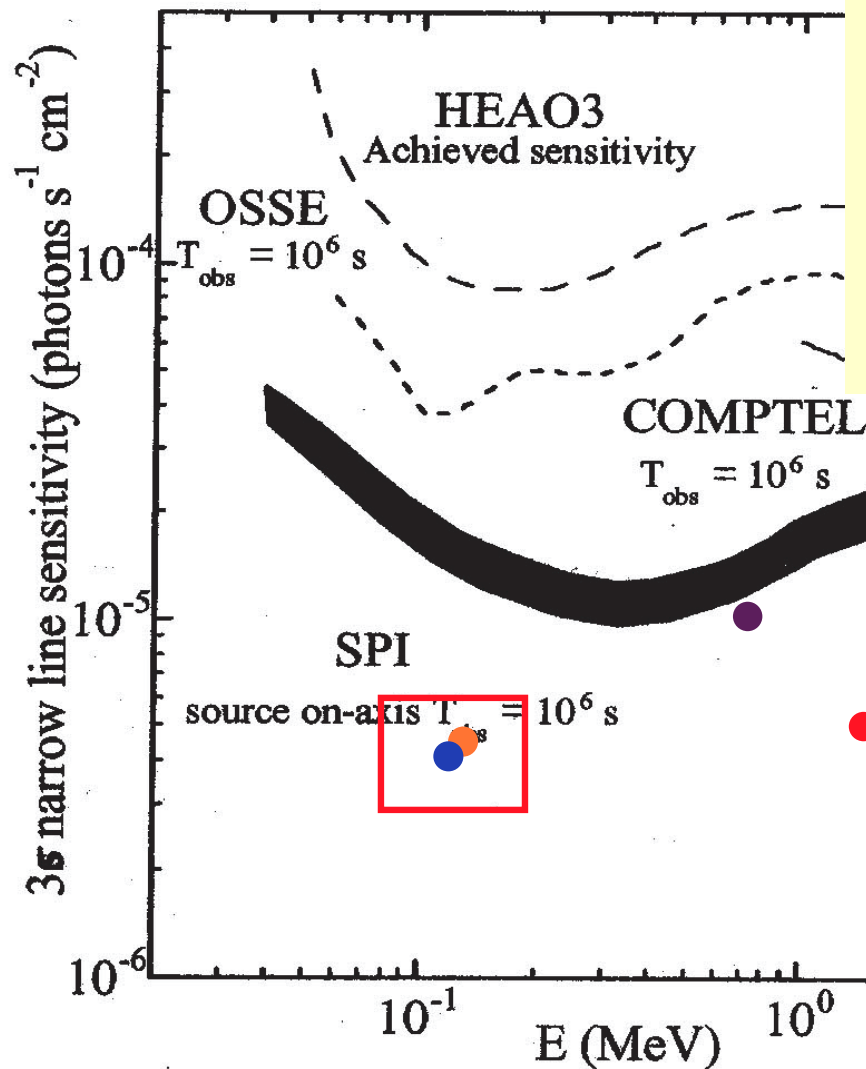
- $^{44}\text{Ti}$  yield derived from observed  $\gamma$ -ray flux with  $t_{1/2}$  of  $\sim 60$  yrs may not necessarily mean the real initial mass.
- The real initial mass is most likely smaller than the "observed" value by a factor **1.5 - 2**, due to retardation of the decay caused by the reverse shock.
- Prospect: recombination & asymmetric explosion (obs. Fesen 2001, Willingale et al. 2002)

# Bolometric light curve for SN 1987A



# Detectability of $^{44}\text{Ti}$ radioactivity from SN 1987A

“upper limit case for 2003”



## ■ 68, 78keV lines

Astro-E2 (HXD)

$3 \times 10^{-5}$  for 100ks obs.

NeXT (To be launched in 2010)

$\sim 10^{-6}$  [cts/cm<sup>2</sup>/s]

## ■ internal conversion

68 keV flux: 8%

reduction from

78 keV flux

**Valid for Cas A, too!**

# Summary : $^{44}\text{Ti}$ in SN1987A

- With 2-week observation-time, it would be difficult for SPI to detect  $^{44}\text{Ti}$  activity.
- If  $^{44}\text{Ti}$  is ionized even partially to H-like state due to the collision, the detection becomes more difficult. Activity may decrease with time according as ionization proceeds.
- Detectability of 68 and 78 keV lines with future X-ray missions.