Ti44 emission from young galactic supernova remnants

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11.2. - 15.2.2019

12th INTEGRAL Conference,

1st AHEAD Gamma-Ray Workshop

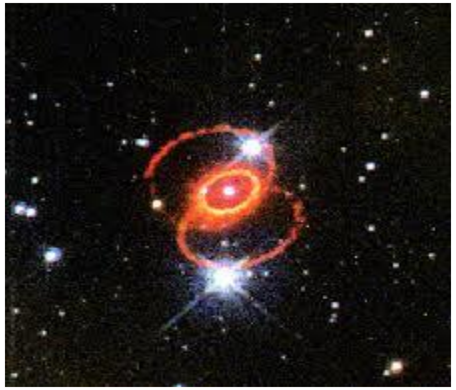
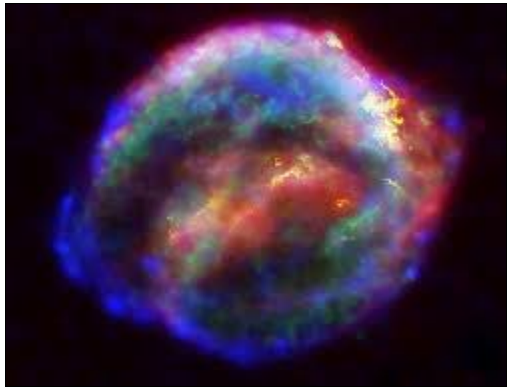
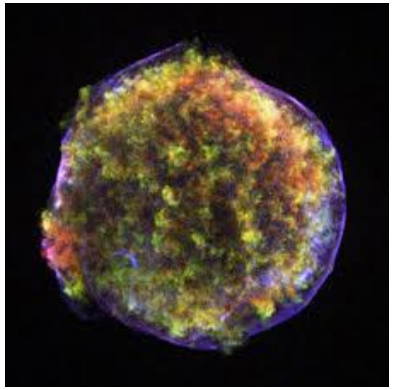
Geneve

Young galactic SNR

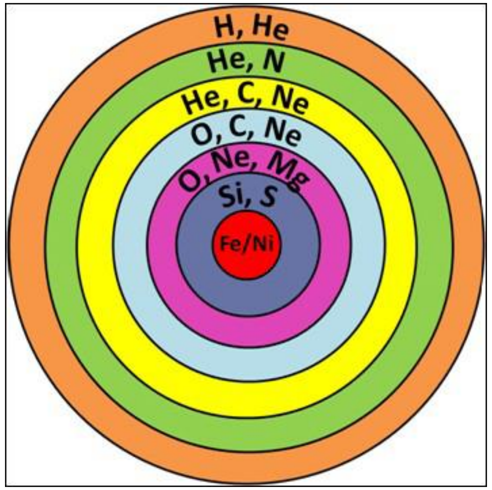
Observable remnants determined by Ti44 half-life of 60a

Name	Age	Distance
Cassiopeia A	~340a	3.4 kpc
Vela Jr.	~700a	250pc
SN1987A	32a	~50 kpc
G1.9+0.3	~110	8.4 kpc
Kepler	415	6.0 kpc
Tycho	447	4.0 kpc

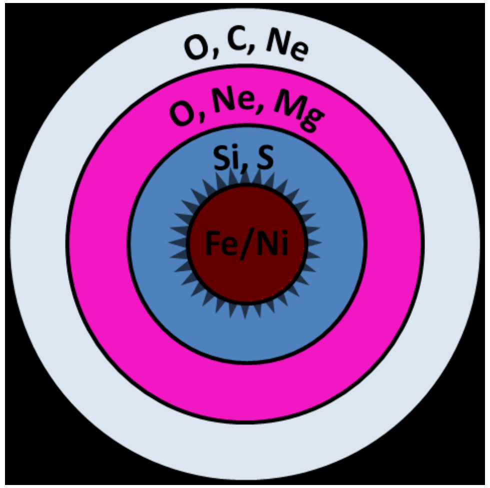


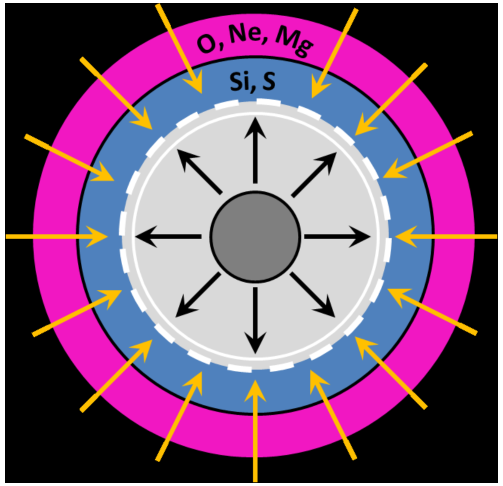
Core Collapse Supernovae



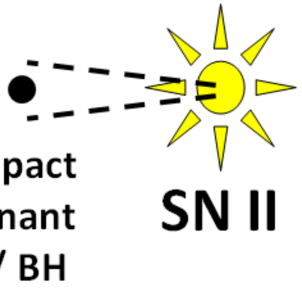
Onion Shell Structure



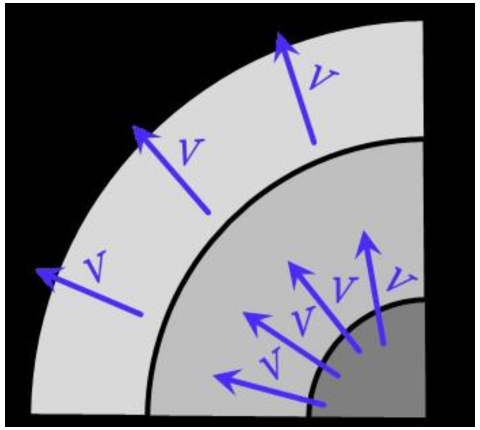
Gravitational Collapse



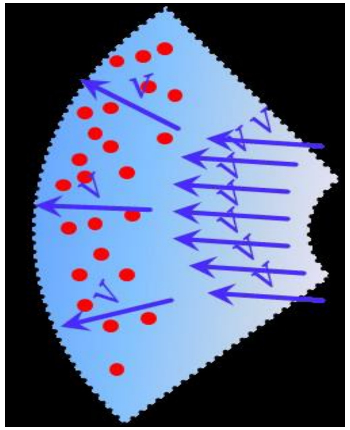
Moving Shockfront



Average expected Ti44 Mass
$10^{-5} - 10^{-4} M_{\odot}$



Neutrino heating



Dissociation of nuclei

Supernova Ia

- Large variety of progenitor models
- Underproduction of intermediates in pure detonation models

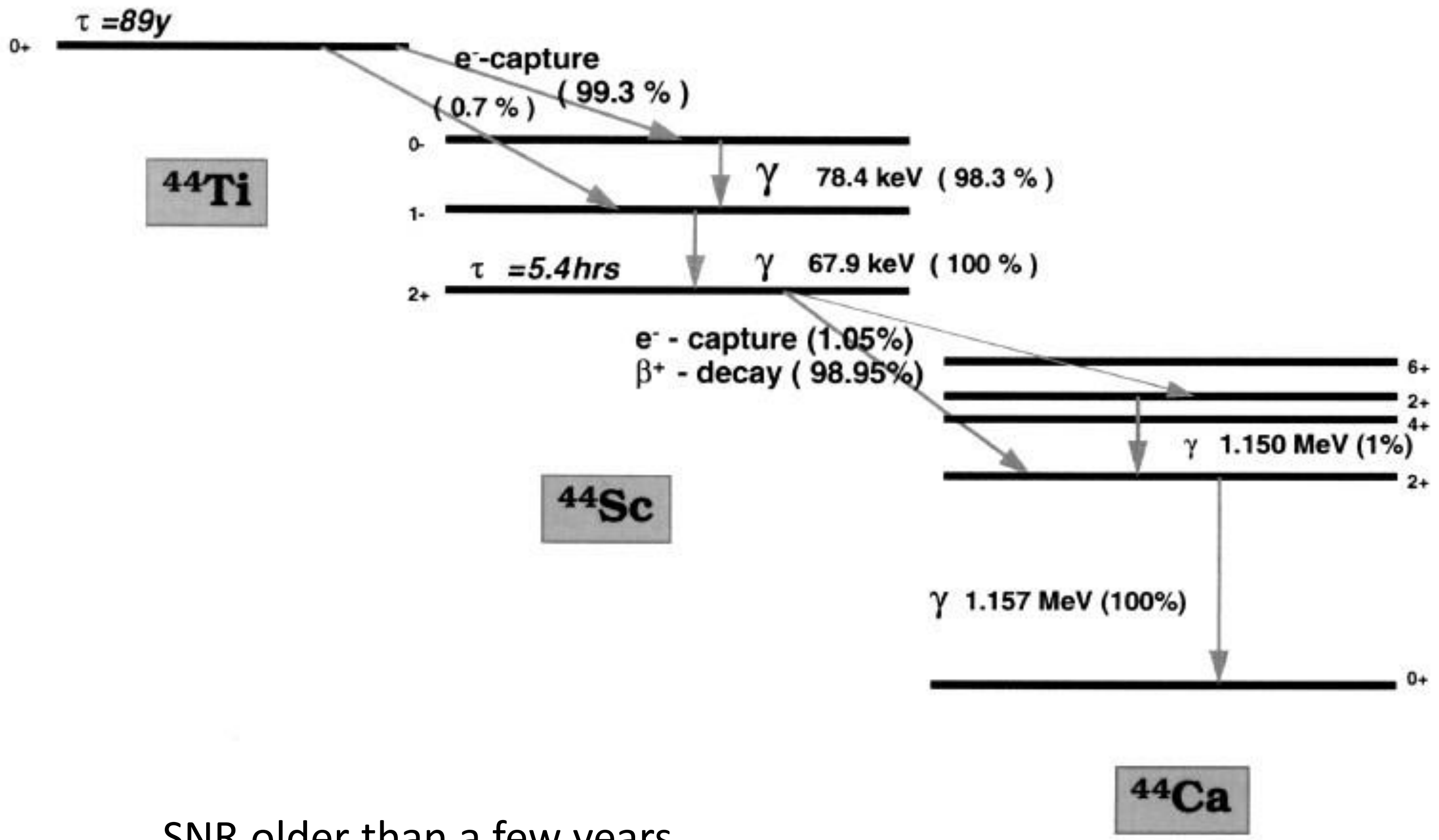
$$0.02 - 2.0 \cdot 10^{-5}\ M_\odot$$

- Double detonation Model suggests $\sim 10^{-3} M_\odot$ Ti44

- Average from delayed detonation and fast deflagration models:

$$7 \cdot 10^{-5}\ M_\odot$$

Ti44 Decay Chain



Two subsequent decays:

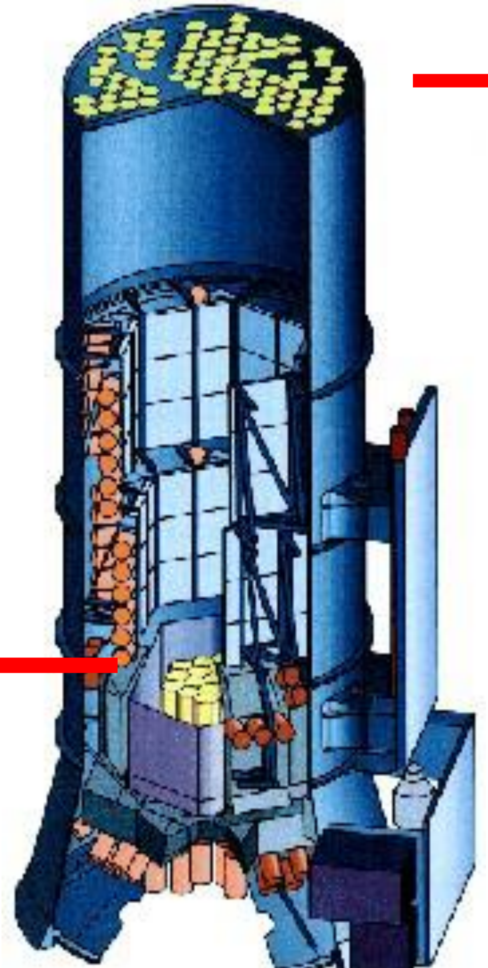
Ti44 at 68 and 78 keV
with halflife 60a

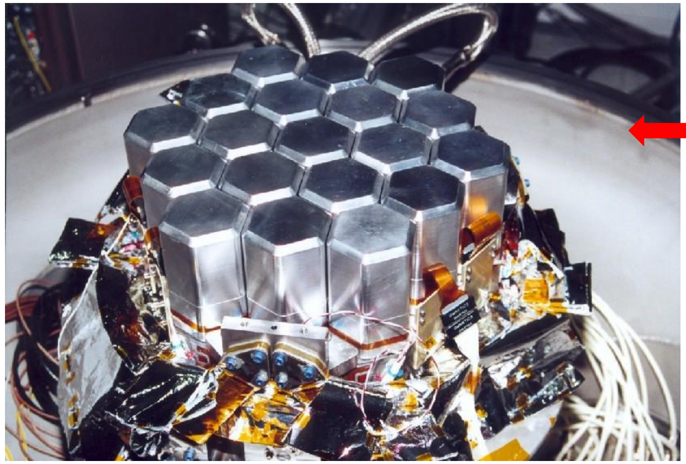
Subsequent Sc44 decay:
1157 keV with halflife 5h

SNR older than a few years
→ Sc44 decay and Ti44 decay produce same flux

γ-Ray Measurements with the Spectrometer on Integral

- 19 High purity Ge Detectors make up the SPI camera
- Energy range: 20-8000keV
- High energy resolution of 2.2keV FWHM at 662keV
- Integrated veto system
- Field of view: 16x16Deg





- γ-rays can not be focused → coded mask telescope:
- Source creates shadowgram in detector array
- Spatial resolution: 2.6 Deg

Distinguish between Background and Sky?

$$D = RxS + B$$

Problem: Data is background dominated →

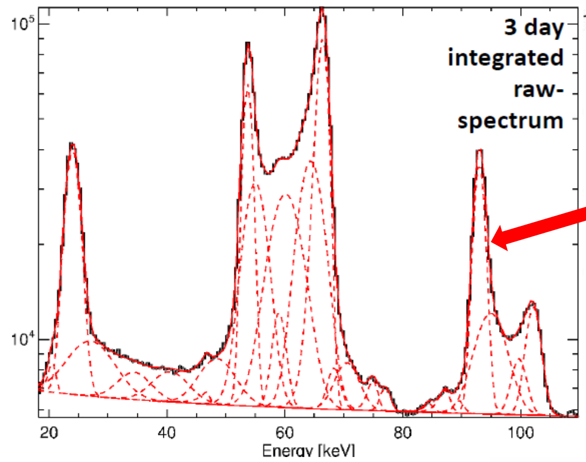
$$S = R-1(D-B) = R-1(0)$$

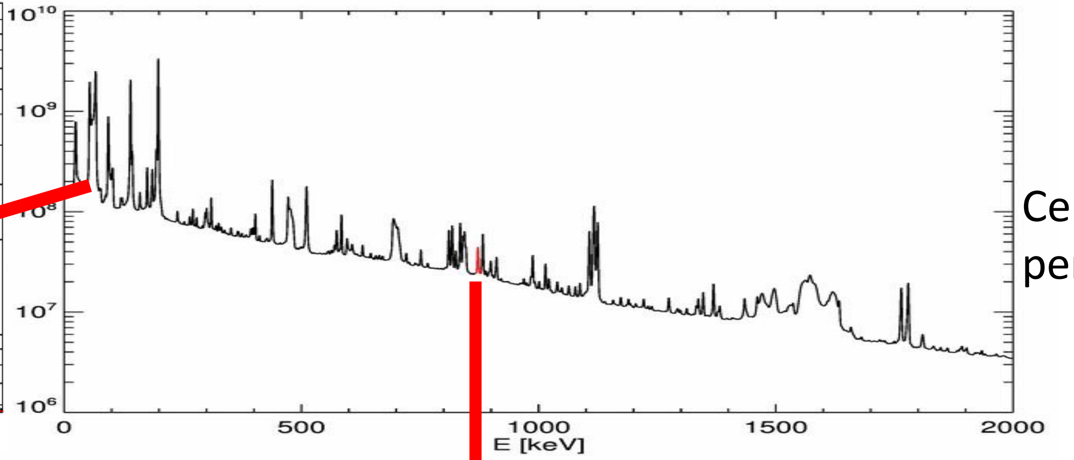
Simultanious determination of background and sky signal necessary

$$D = \alpha(RxS) + \beta B$$

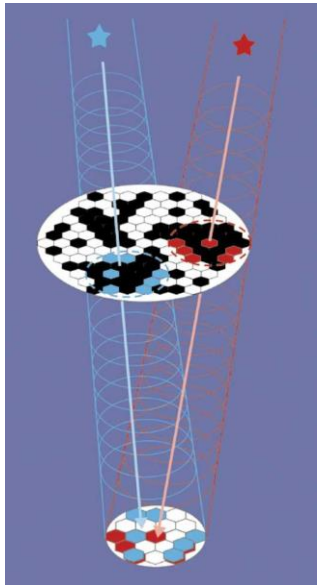
- Elaborate background model that self consistently describes the physical processes in the satellite needed.

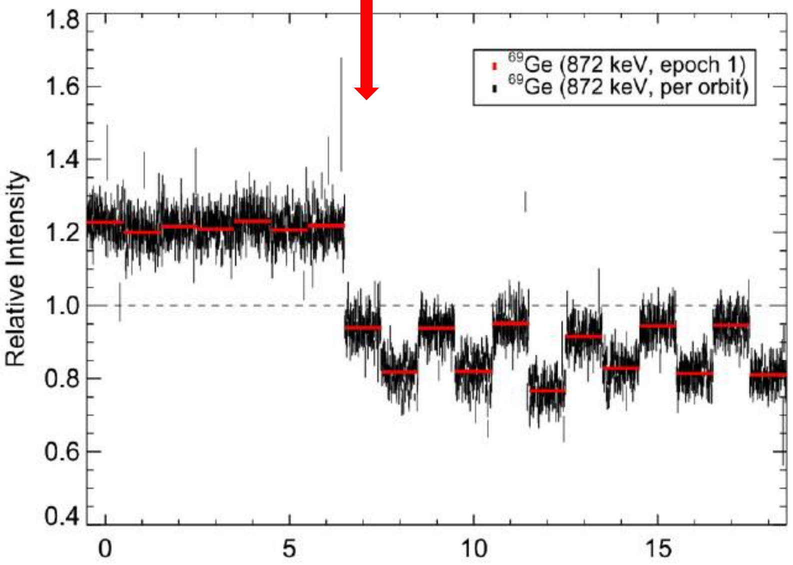
Background Modeling



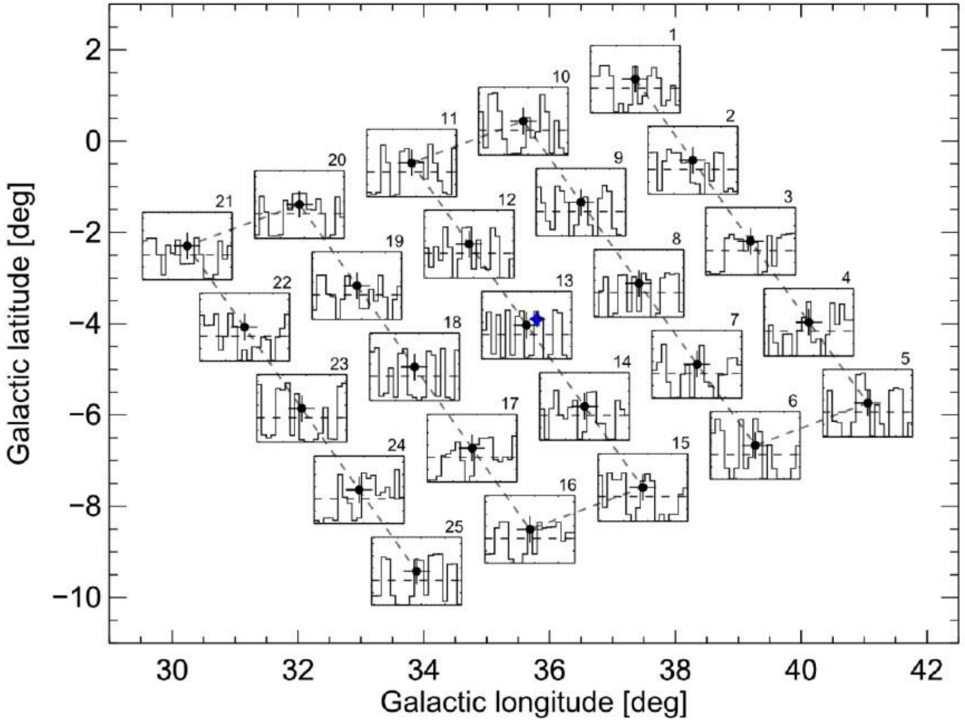


Celestial Pattern changes per dithering



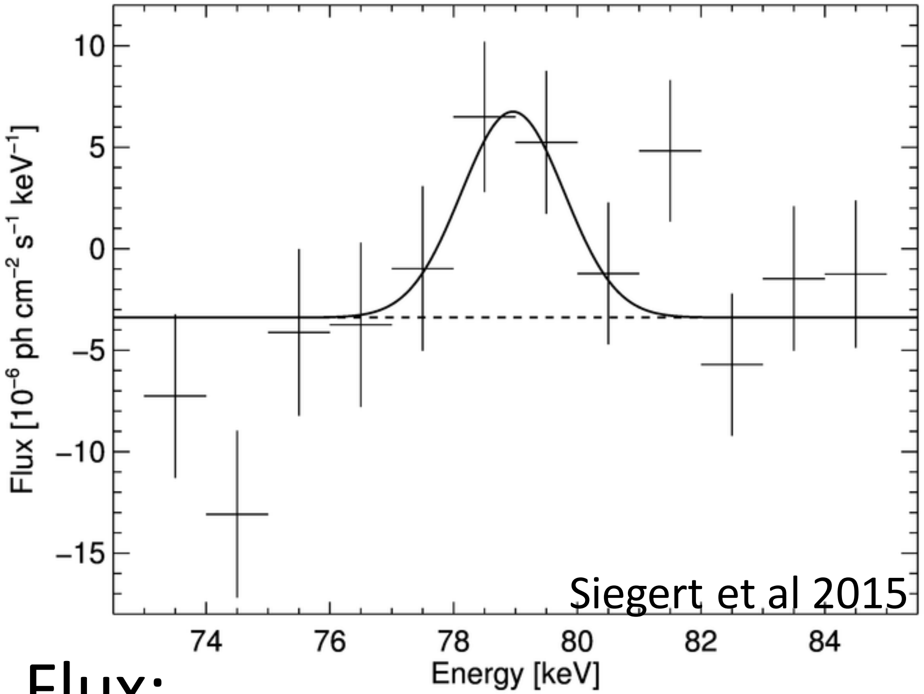


Background Pattern remains constant for long periods of time



Cassiopeia A

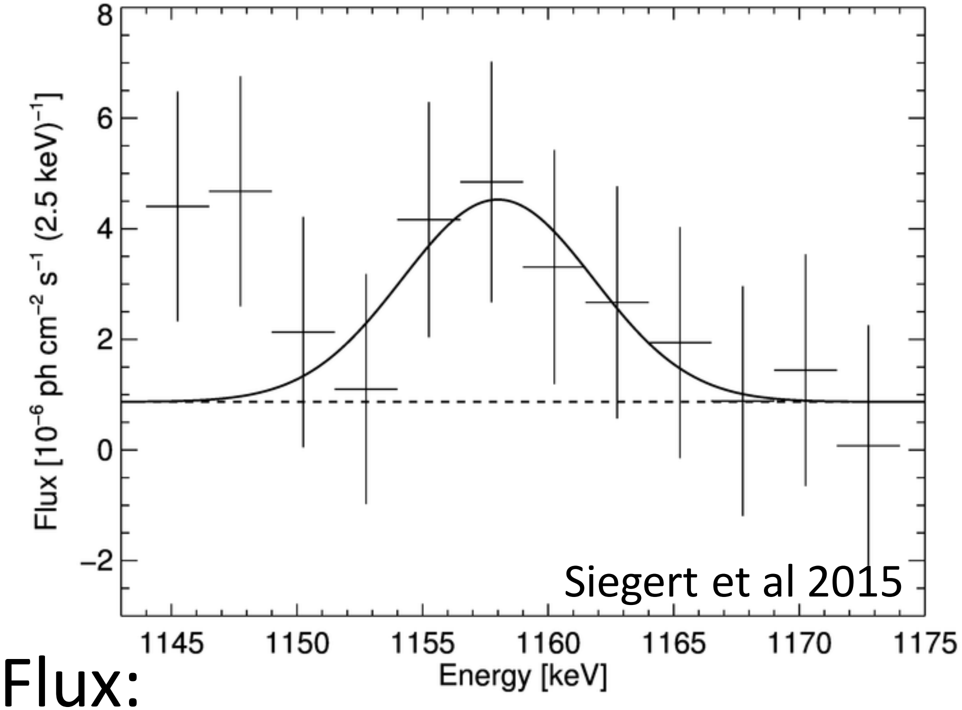
Spectra obtained at the position of Cassiopeia A at a remnant age of ~340a



Flux:
$(2.1 \pm 0.4) \cdot 10^{-5}\, ph/cm^2\ /\ s$

Mass: $(1.5 \pm 0.4) \cdot 10^{-4}\, M_{\odot}$

Vbroad: $(4300 \pm 1600) km/s$

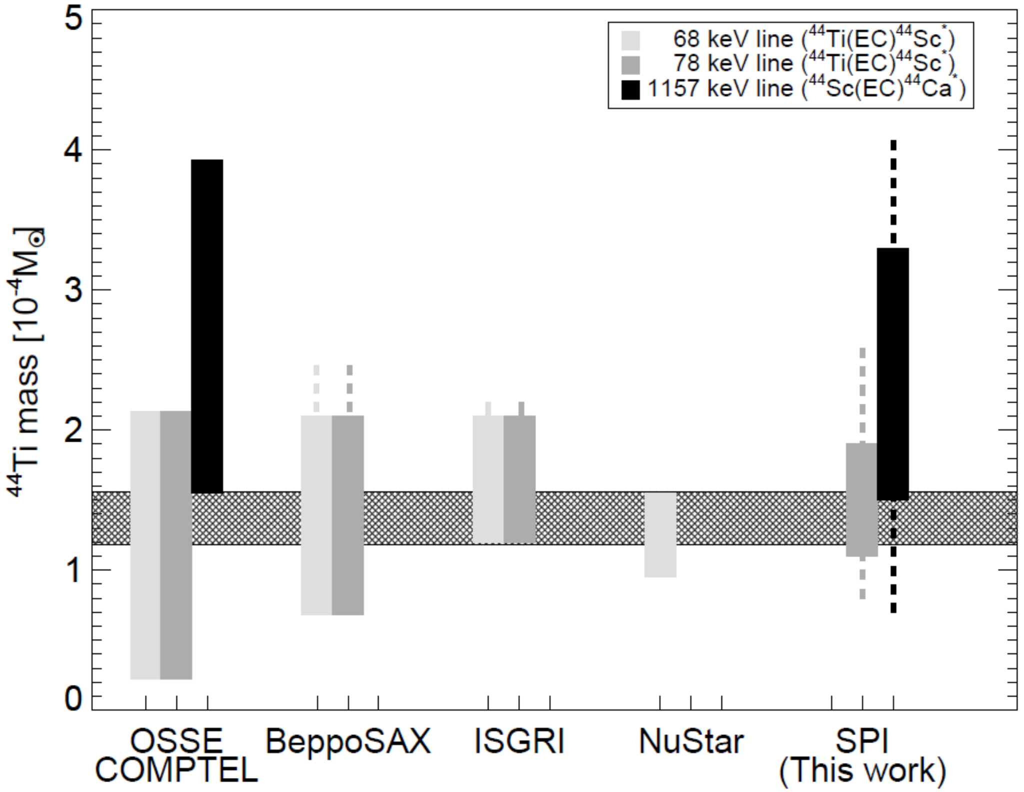


Flux:
$(3.5 \pm 1.2) \cdot 10^{-5}\, ph/cm^2\ /\ s$

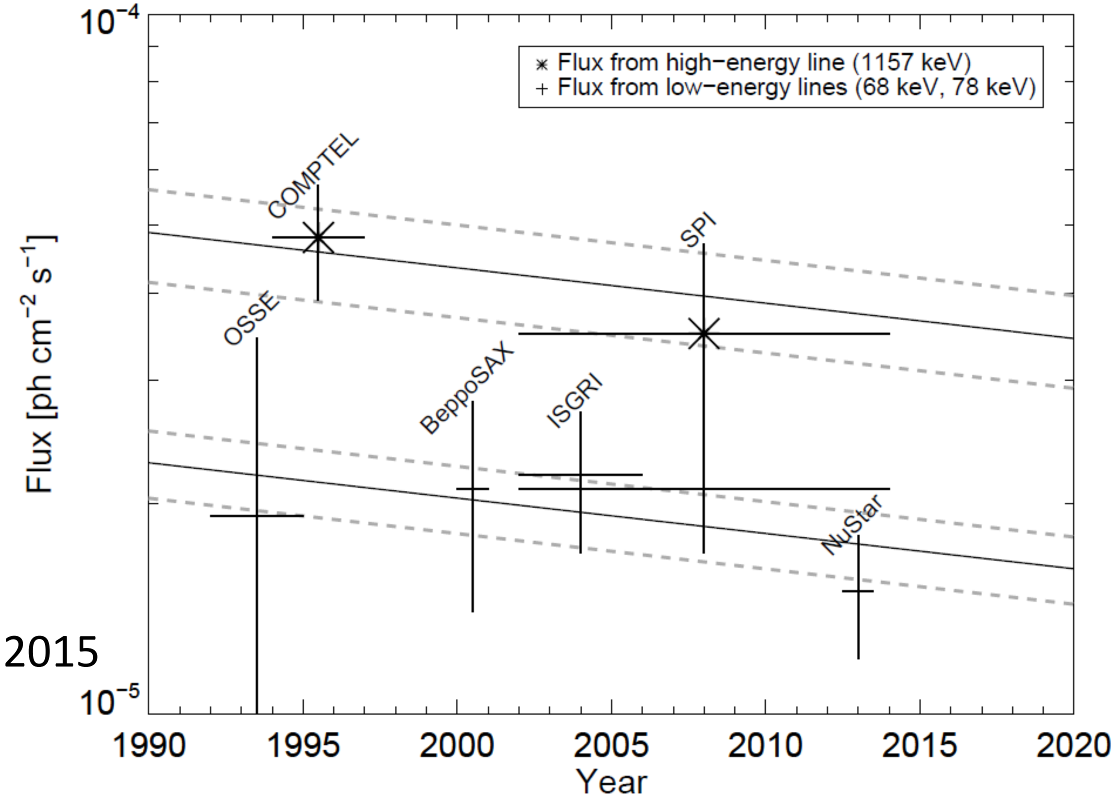
Mass: $(2.4 \pm 0.9) \cdot 10^{-4}\, M_{\odot}$

Vbroad: $(2200 \pm 400) km/s$

Mean Mass



Siegert et al 2015



Combining with previous studies:

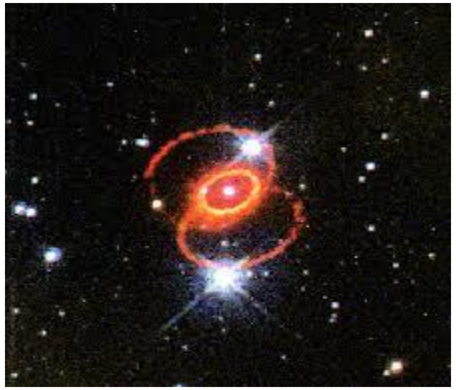
$$(1.37 \pm 0.19) \cdot 10^{-4}\, M_\odot$$

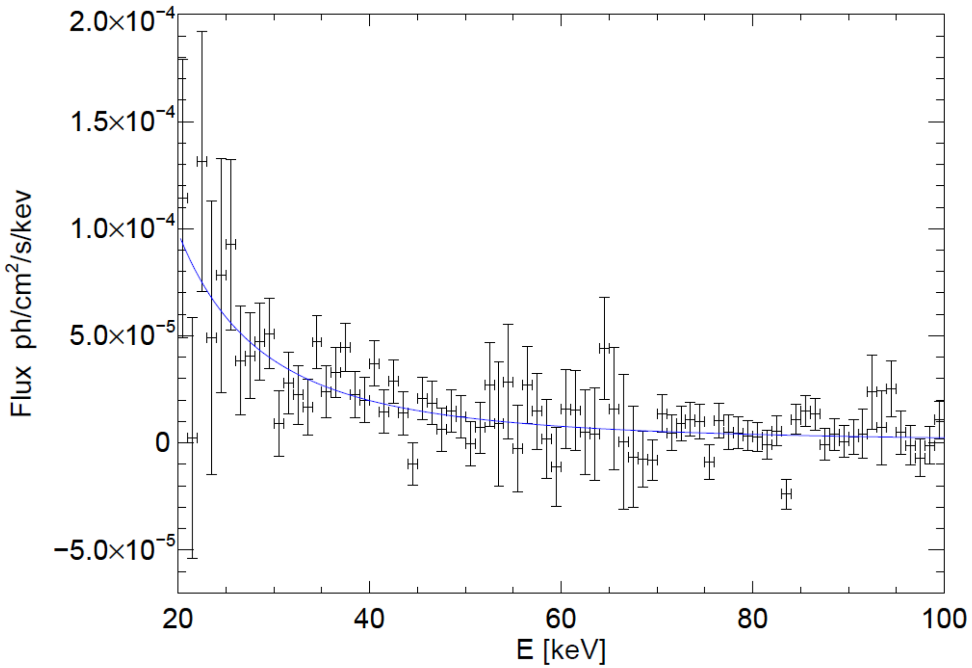
Ejected Ti44 Mass higher than expected Ti44 yields from simulations!

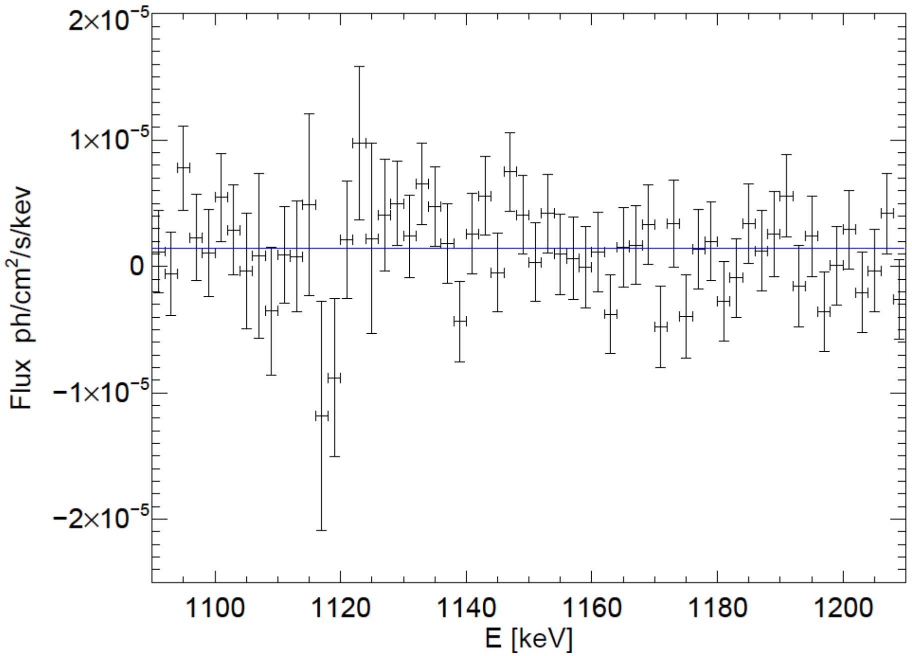
Systematically higher ejecta mass in 1157keV

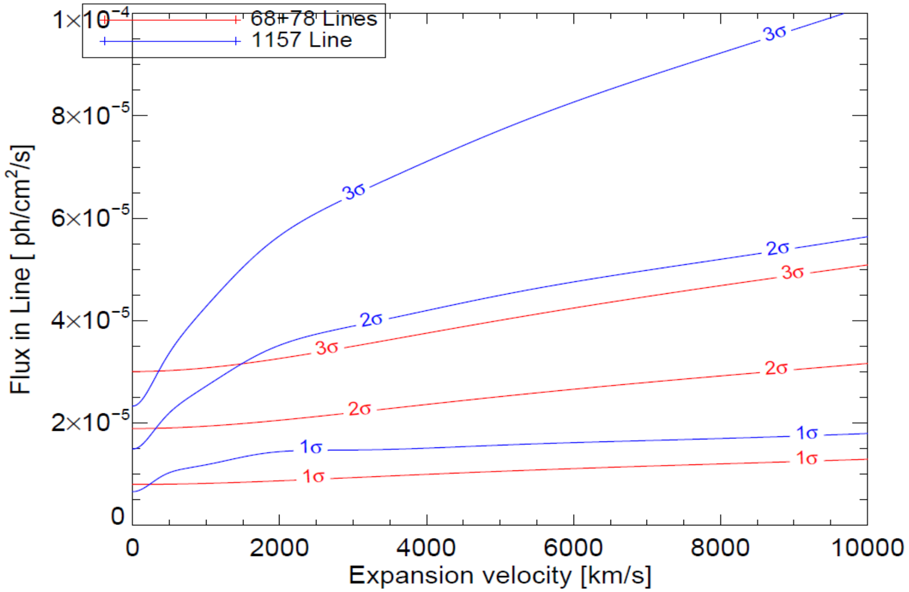
Different explosion kinematics

SN1987A



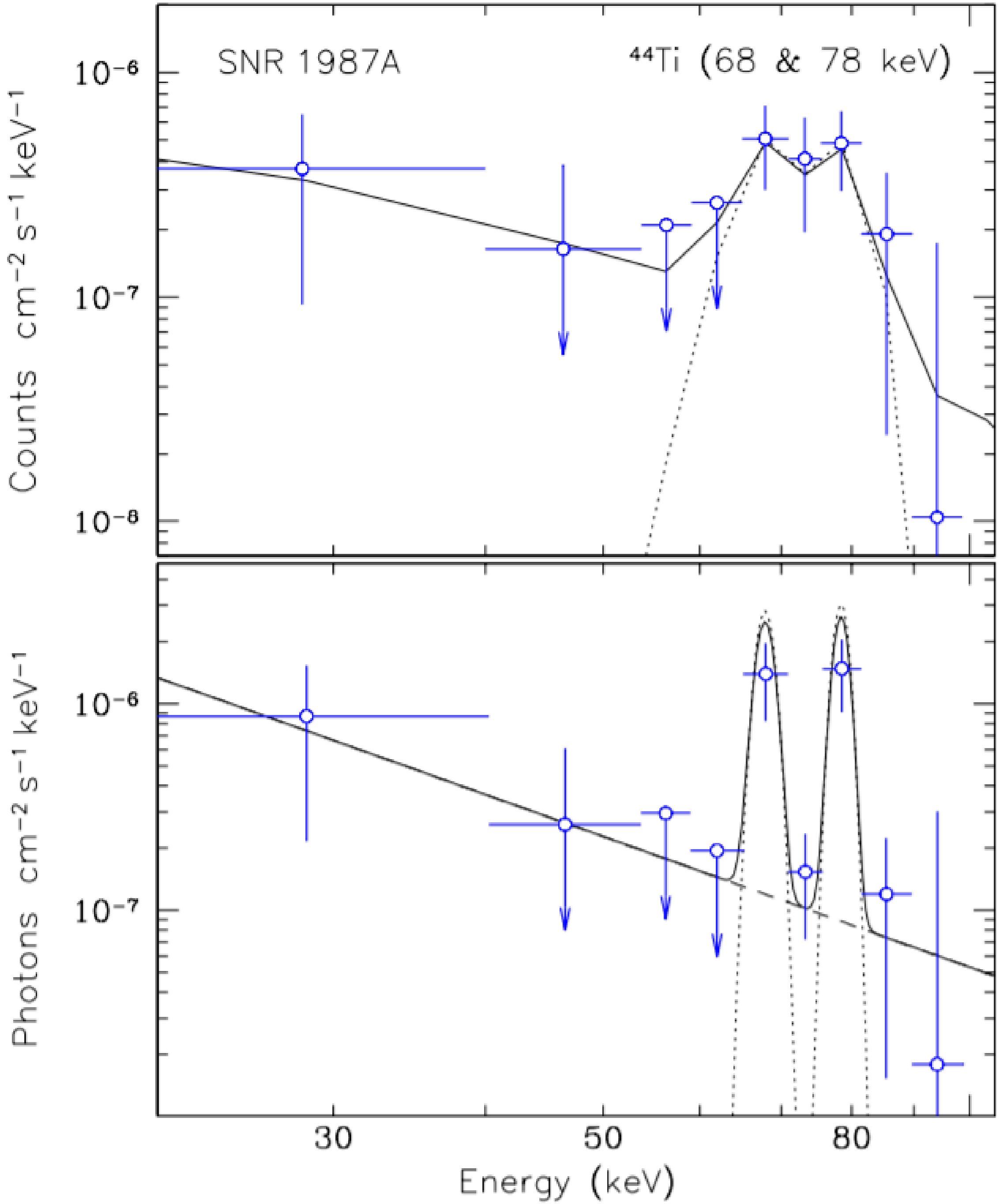


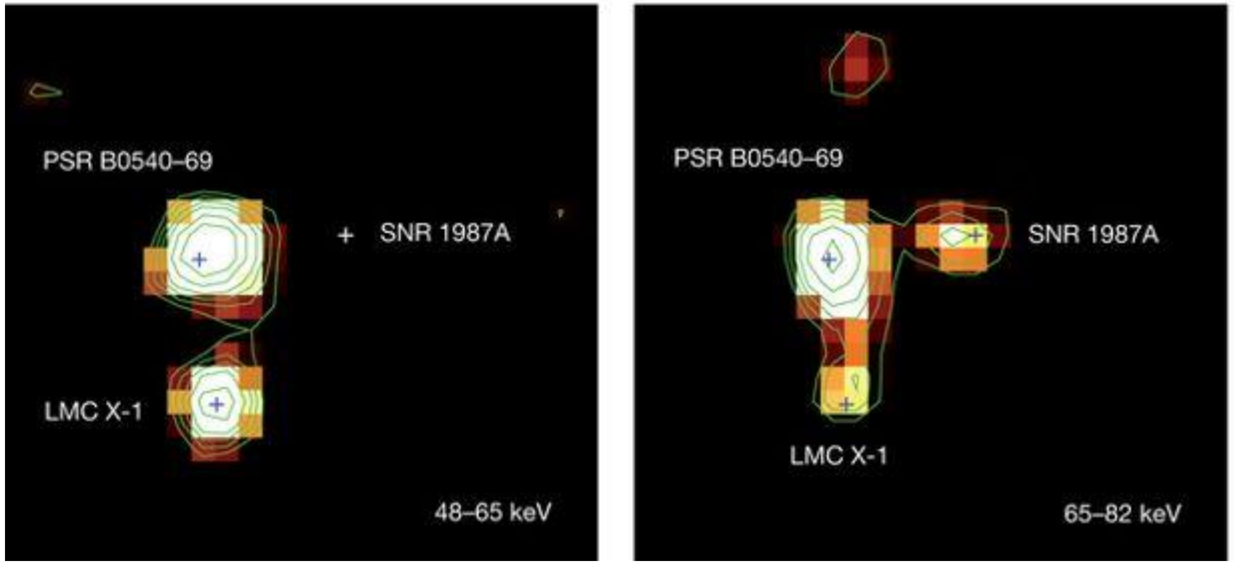




Age 30a
Distance of 50kpc -> high emission yield below sensitivity of SPI
No detection with SPI (preliminary): upper limits at 3000km/s FWHM
1157 kev: $6.2 \cdot 10^{-5}\ ph/cm^2\ /\ s$ 78kev: $3.5 \cdot 10^{-5}\ ph/cm^2\ /\ s$

→ Mass range of $> 10^{-3} M_{\odot}$ Ti44
More observation time needed for more stringent constraints





Grebenev 2012

4σ Detection of Ti 44 in 65-82 keV band with IBIS/ISGRI:
Flux: $(1.7 \pm 0.4) \cdot 10^{-5}\ ph/cm^2\ /\ s$(68+78kev),
mass: $(3.5 \pm 0.8) \cdot 10^{-4}\ M_{\odot}$

Expansion velocity of 1700km/s

Vela Jr.

- 5.6σ Detection with Comptel during all-Sky Ti survey (Iyudin 1999)
- Close by 200pc at 680y age

  Flux: $(3.8 \pm 0.7) \cdot 10^{-5}\, ph/cm^2\ /\ s$

- Gaussian emission profile assumed

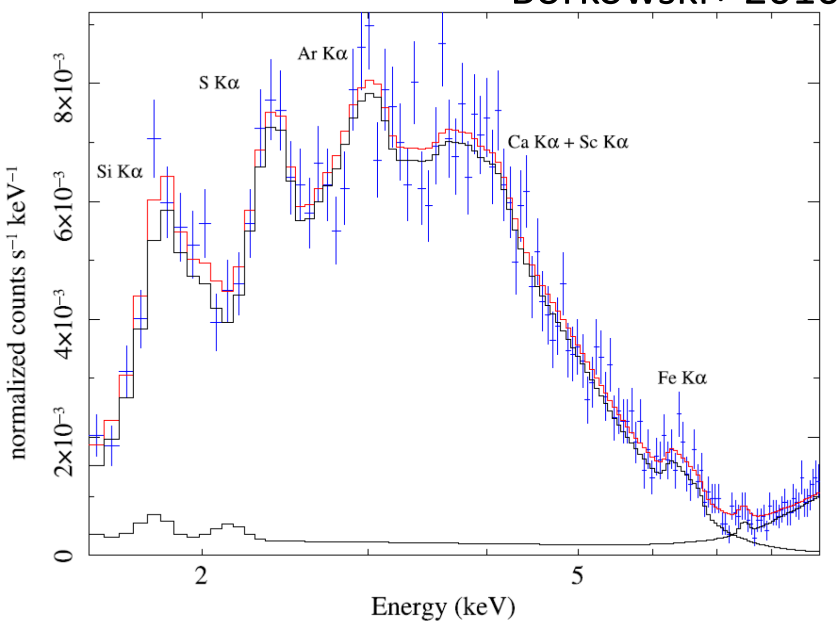
- SPI 3σ upper limits results (preliminary):

  $3.6 \cdot 10^{-5}\, ph/cm^2\ /\ s$ at 78 keV (Below Comptel Data)

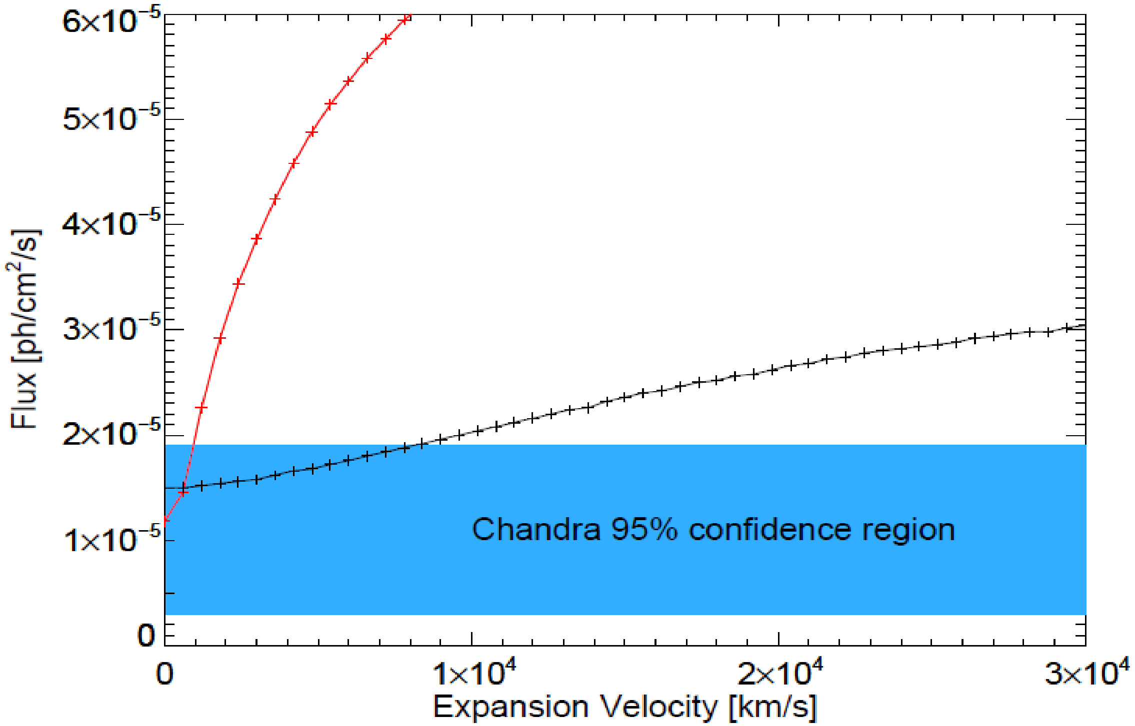
  $9.3 \cdot 10^{-5}\, ph/cm^2\ /\ s$ at 1157 keV

G1.9+0.3

Borkowski+ 2010



- Youngest know SNR at 120a age at galactic center
- Detection of Sc44 4.1keV flurescence line implies $(1-7)\cdot 10^{-5}\,M_{\odot}$ Ti44 in remnant
- (equivalent to 0.3-1.9 $\cdot\, 10^{-5}\, ph/cm^2\,/\,s$ in hard X-Ray and γ-lines)



SPI 3σ upper limits (preliminary at 5000km/s):

$1.7\cdot 10^{-5}\, ph/cm^2\,/\,s$ at 78 keV

$6.4\cdot 10^{-5}\, ph/cm^2\,/\,s$ at 1157 keV

Tycho and Kepler

- SPI limits:

$1.4 \cdot 10^{-4} ph/cm^2 / s$ at 1157keV

$2.4 \cdot 10^{-5} ph/cm^2 / s$ at 78keV

Depending on distance:

$few \cdot 10^{-5} M_{\odot} - \sim 5 \cdot 10^{-4} M_{\odot}$ Ti44

- SPI limits:

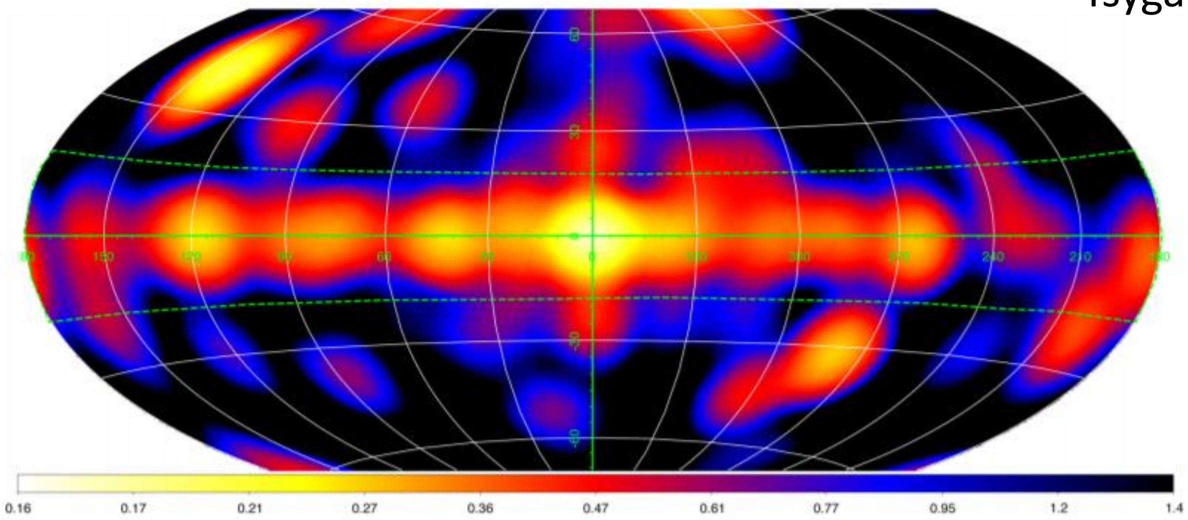
$4.9 \cdot 10^{-5} ph/cm^2 / s$ at 1157kev

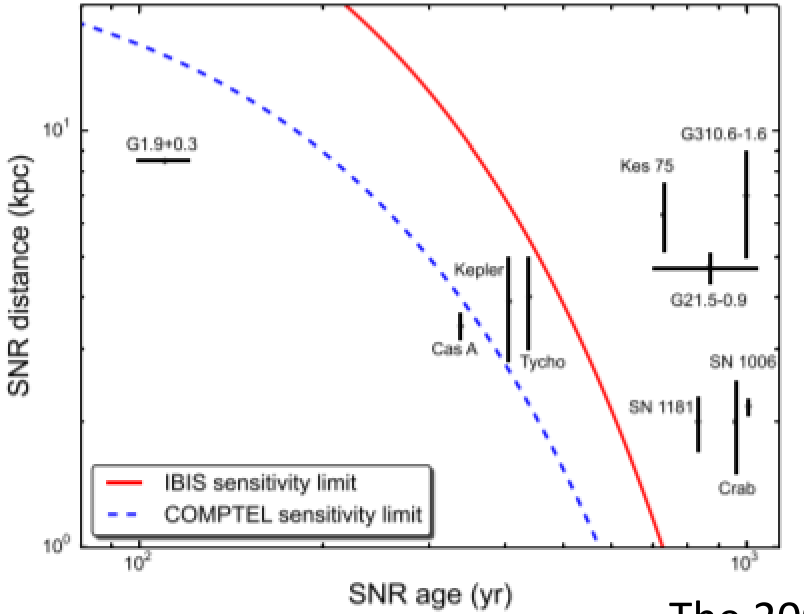
$2.6 \cdot 10^{-5} ph/cm^2 / s$ at 78 keV

Synthesized Ti44 $\sim 5 \cdot 10^{-4} M_{\odot}$

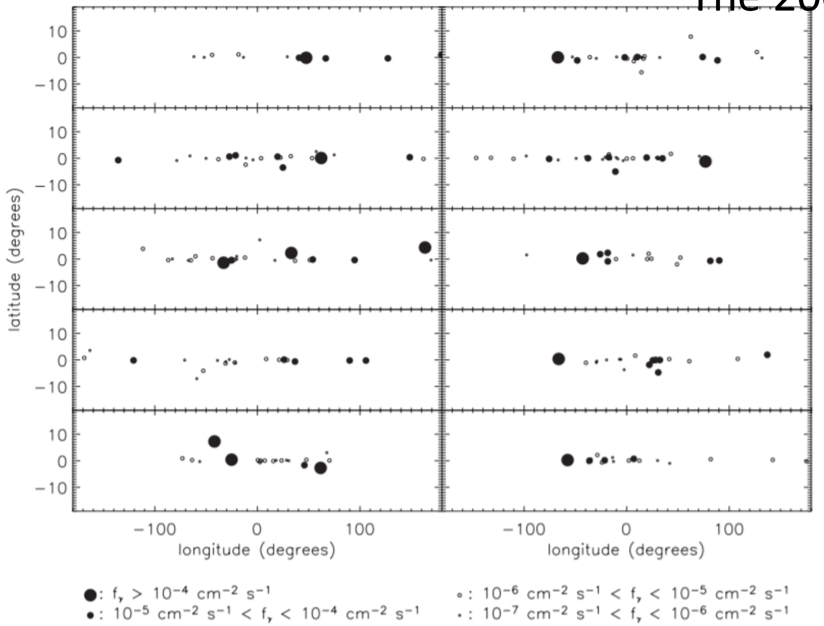
SPI and IBIS results combined

Tsygankov 2016





The 2006



- SPI upper limits in good agreement with IBIS limits (Tsygankov 2016)
- No detection of new Ti44 emitting sources in IBIS all sky survey
- Contrast to expected sources by from typical supernova rates
- Where are the sources? Ti44 producing Supernovae exceptional events?
- Work in progress: Survey with SPI in both energy range!

Summary

- 2 CC-SN (CasA, SN1987A) found with more than $10^{-4} M_{\odot}$ Ti44 ejecta above masses expected from simulations
- Double detonation model ruled out for young galactic SNIa
- Ti44 emitting SNe possibely rare events

Remnant	Synthized Ti44 Mass
CasA	$1.39 \cdot 10^{-4} M_{\odot}$
SN1987A	$\sim 10^{-3} M_{\odot}$
Vela Jr.	$< 5 \cdot 10^{-5} M_{\odot}$
G1.9+0.3	$< 5 \cdot 10^{-5} M_{\odot}$
Tycho	$\sim few \cdot 10^{-5} M_{\odot} - \sim 5 \cdot 10^{-4} M_{\odot}$
Keppler	$\sim 5 \cdot 10^{-4} M_{\odot}$