II. Observations

From 1912 to 1950:

* 1913: “High-altitude” radiation (*Hess 1914, Kolhoerster 1914*)
* 1920s: Term “cosmic rays” (Millikan)
* 1929: corpuscular nature of the radiation (with Geiger-Müller counters, Bothe & Kolhörster 1929)
* 1940-50's: balloon and rocket experiments

Predictions in the 1950's:

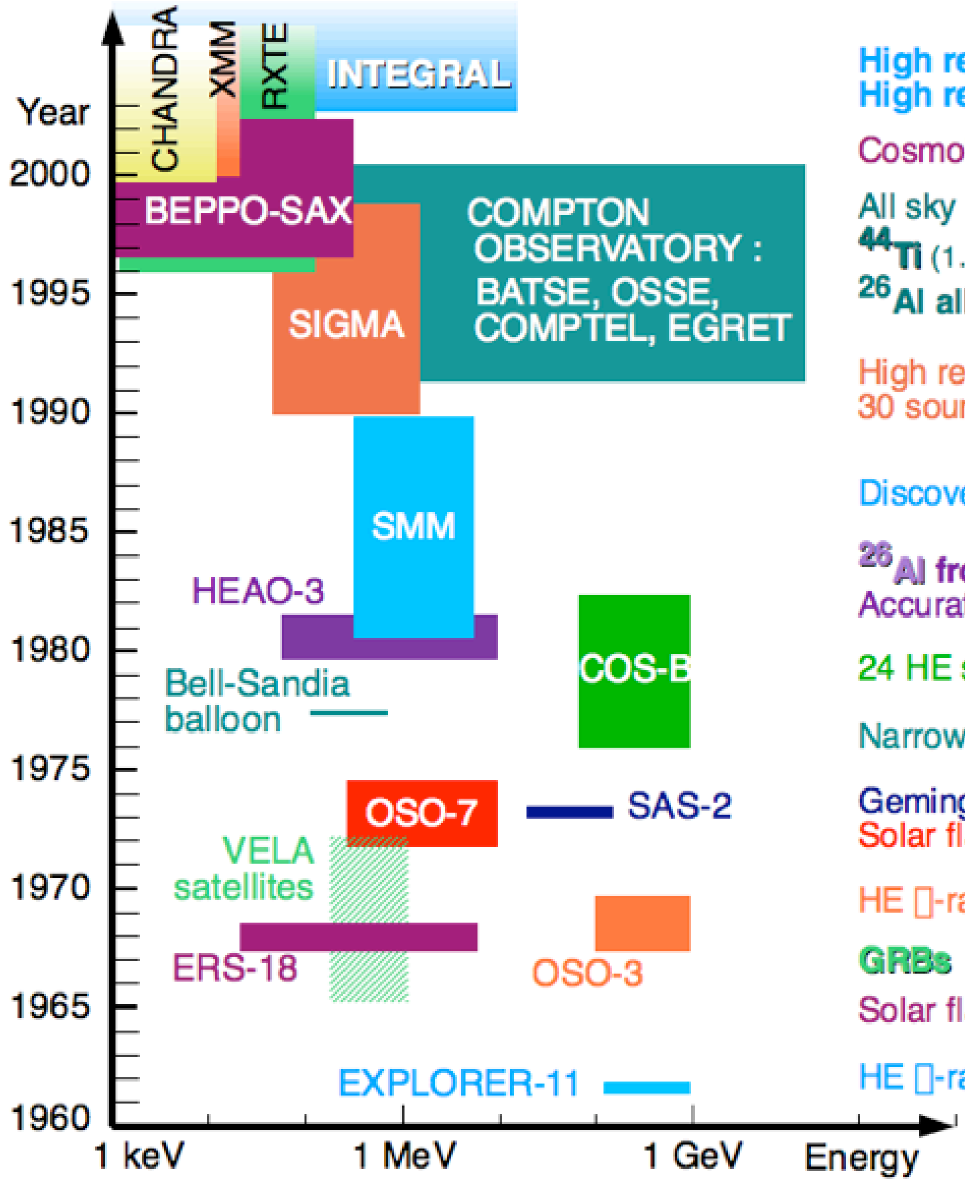
* 1952: Diffuse Galactic γ-ray emission (*Hayakawa 1952*)
  Interstellar γ-ray emission (*Hutchinson 1952*)
* 1958: Cosmic γ-ray sources (*Morrison 1958*) :

(Morrison 1958, from Schoenfelder 2000)

Source		Predicted Fluxes (ph. cm^{-2} sec^{-1})	Actual Fluxes (ph. cm^{-2} sec^{-1})	
Solar flares 10-100 MeV	:	0.1 to few	~ 0.01	
2.223 MeV	:	1 to 100	few 0.1	
Crab Nebula (g-ray lines)	:	~ 10^{-2}	< few 10^{-5}	
Radio Galaxies 10-100 MeV	:	0.1 to 1	□ 10^{-5}	(Cen A)
511 keV	:	0.1 to 1	2.6 x 10^{-5}	(Cen A)

→ *1960s: First balloons and satellites experiments*

High Energy Missions: Highlights



High resolution imaging (12')
High resolution spectroscopy

Cosmological origin of GRBs

All sky coverage;
^{44}Ti (1.156 MeV) and ^{57}Co (122 keV) from Cas A
^{26}Al all sky map ... and ^{44}Ti from RX 0852-4622 ?

High resolution images (13')
30 sources in GC

Discovery of ^{56}Co from SN 1987a

^{26}Al from GC
Accurate 511 keV line profile from GC

24 HE sources in Milky Way

Narrow (few keV) **511 keV line**

Geminga
Solar flare γ-ray line

HE γ-rays from Milky Way

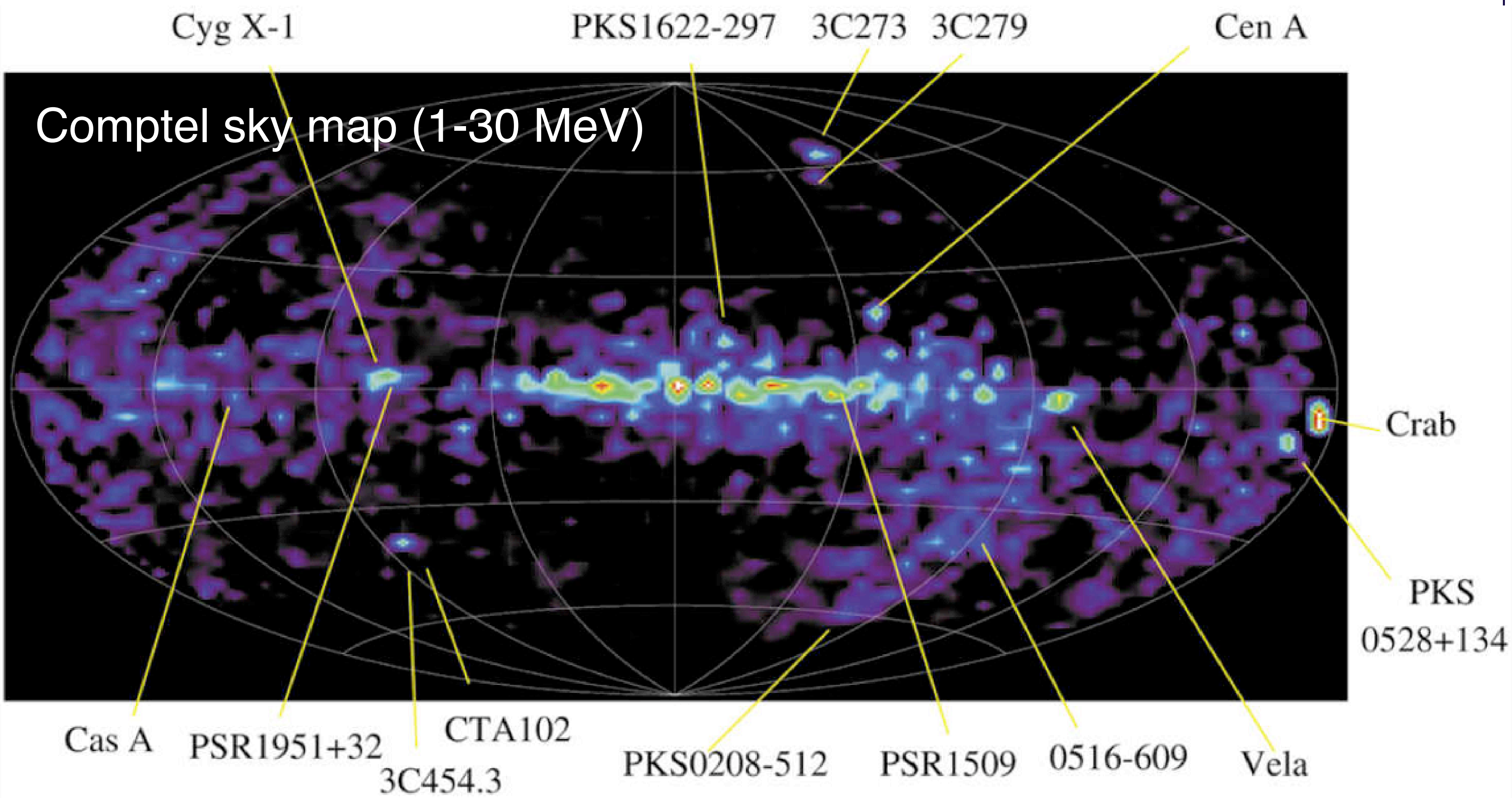
GRBs

Solar flare continuum γ-rays

HE γ-rays from space

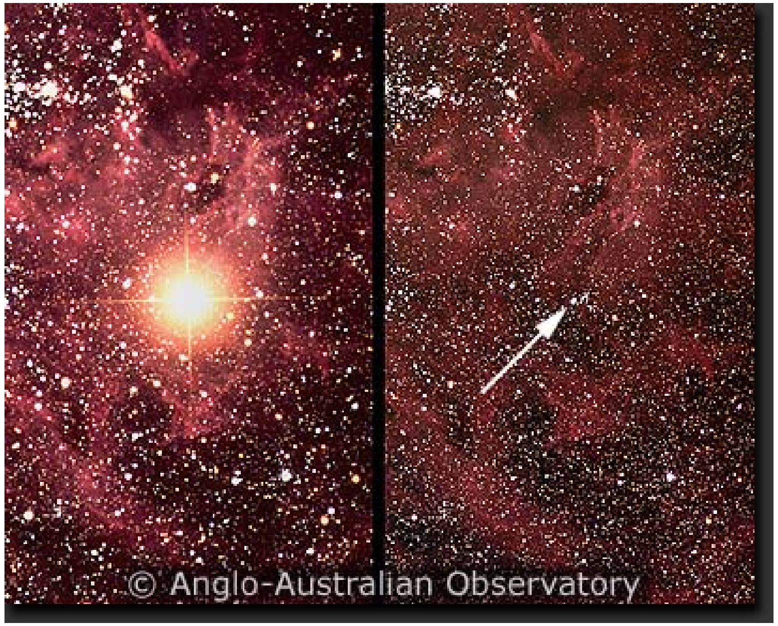
Accronyms:
GC : Galactic Center
GRB : Gamma ray Burst
HE : High Energy

High Energy Missions: Highlights

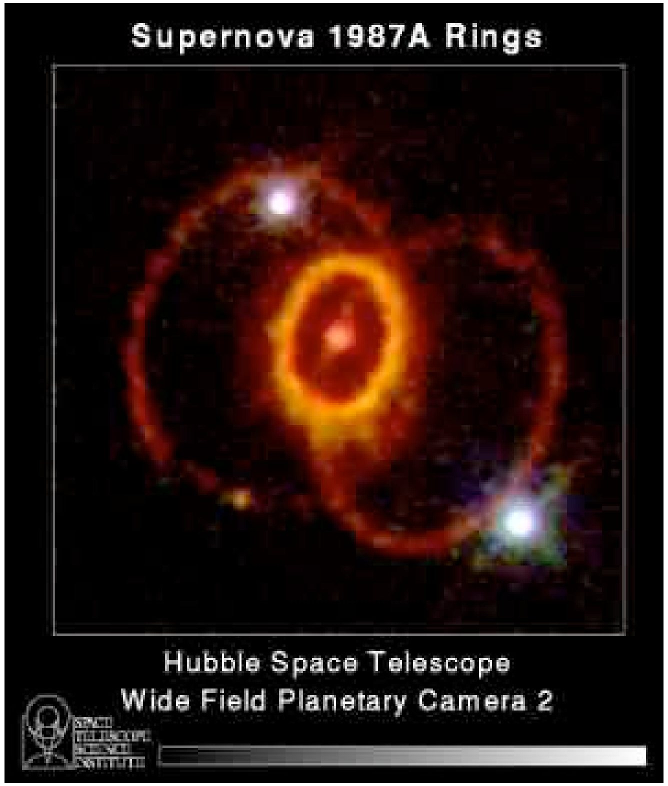


→ *difficult to observe in gamma-rays.*

SN 1987A: Generalities



- 23 Feb. 1987 in LMC (52 kpc)
- Brightest SN since Kepler's SN in 1604. M_{app}= 2.7
- Progenitor: Red star (~ 20 M☉, ~10^6 y)



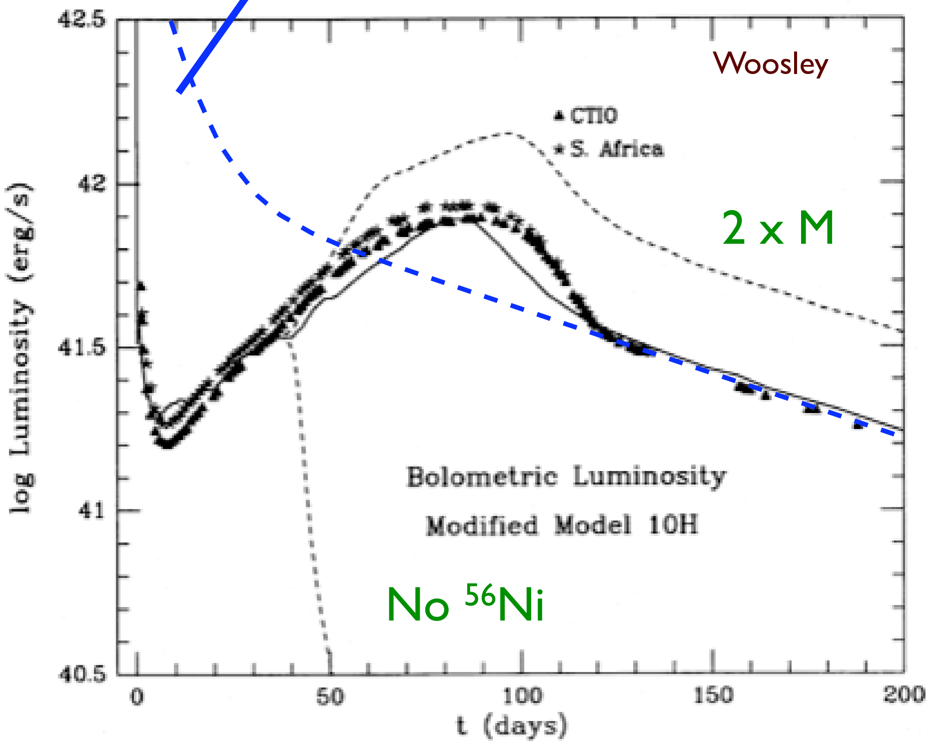
* **25 neutrinos** detected around 7h36 on Earth (Kamiokande II - Japan, IMB,- US, Baksan - Russia)
- First detection of neutrinos outside Solar System
- Confirmed SN theories

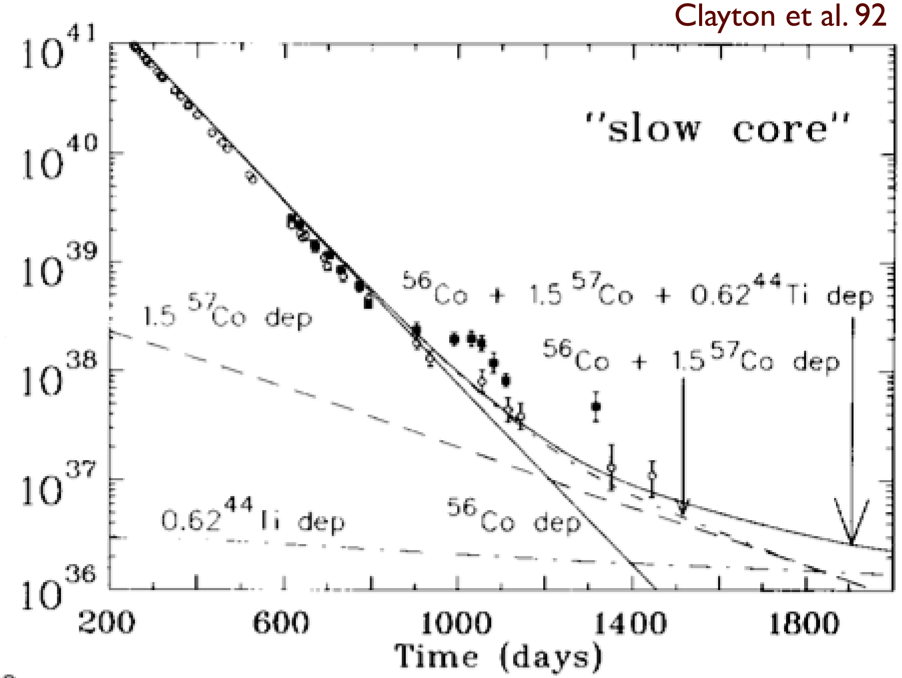
* **Rings**
- Inner ring: gas and dust heated by SN (R = 0.7 ly)
- Outer rings: ? (R = 1.4 ly), HST1994

* **NS expected** from neutrinos.
But no observational evidence (no pulsar detected...)

SN 1987A: The lightcurve

if 100% optical conversion and escape of decay energy of ^{56}Ni and ^{56}Co (0.07 Mo)



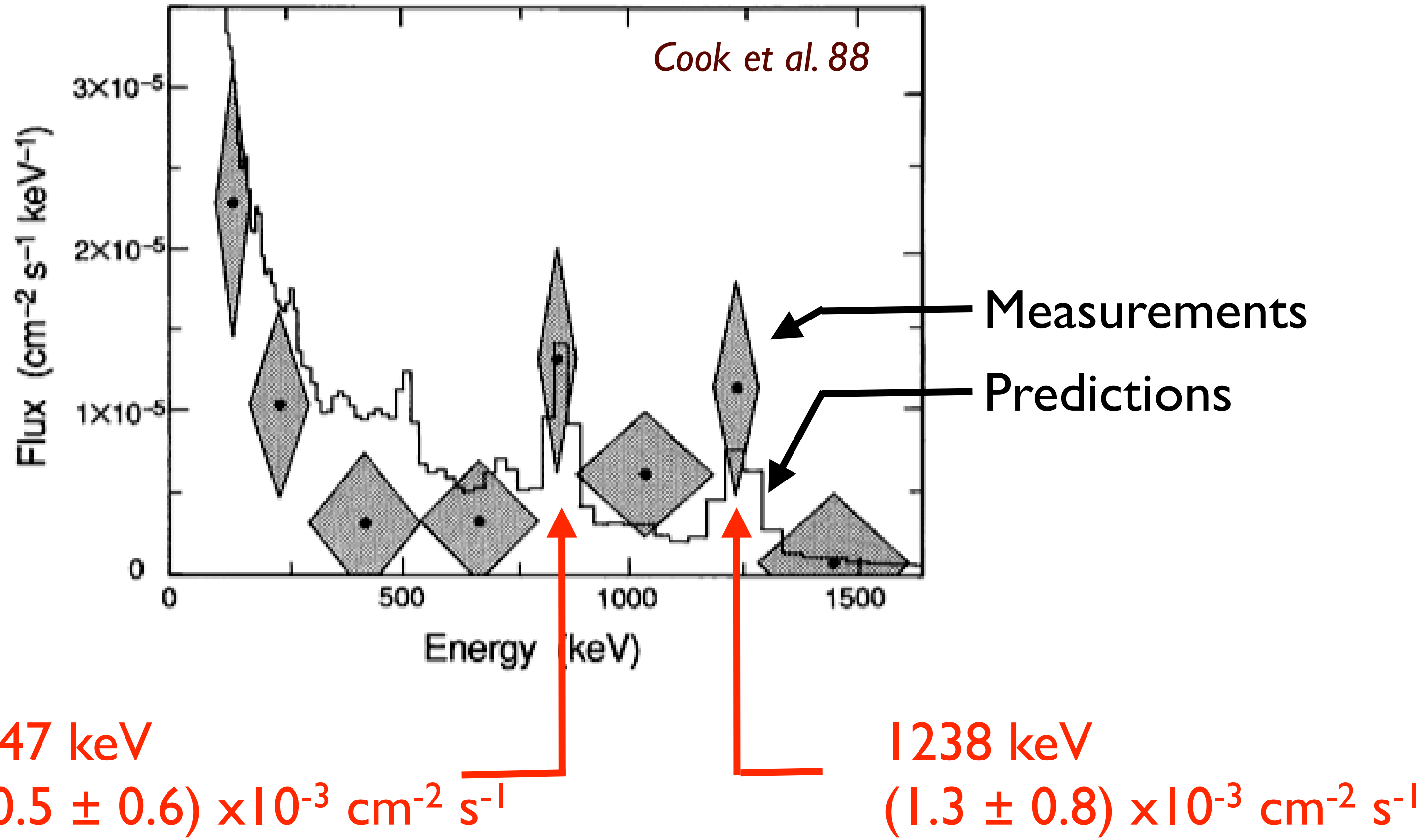


At time of explosion:

- He core mass: 6±1 M$_\odot$
- Fe core mass : 1.45±0.15 M$_\odot$
- formed NS : 1.40 ± 0.15 M$_\odot$
- M_{env}: 5-10 M$_\odot$
- 2-3 x 10^{53} ergs of neutrinos
- 1.5±0.5 M$_\odot$ of heavy elements ejected, moving slowly (<1500 km/s)

SN 1987A: ^{56}Co

One of the balloon experiments (@98 d): GRIP (Caltech Gamma-Ray Imaging Payload)

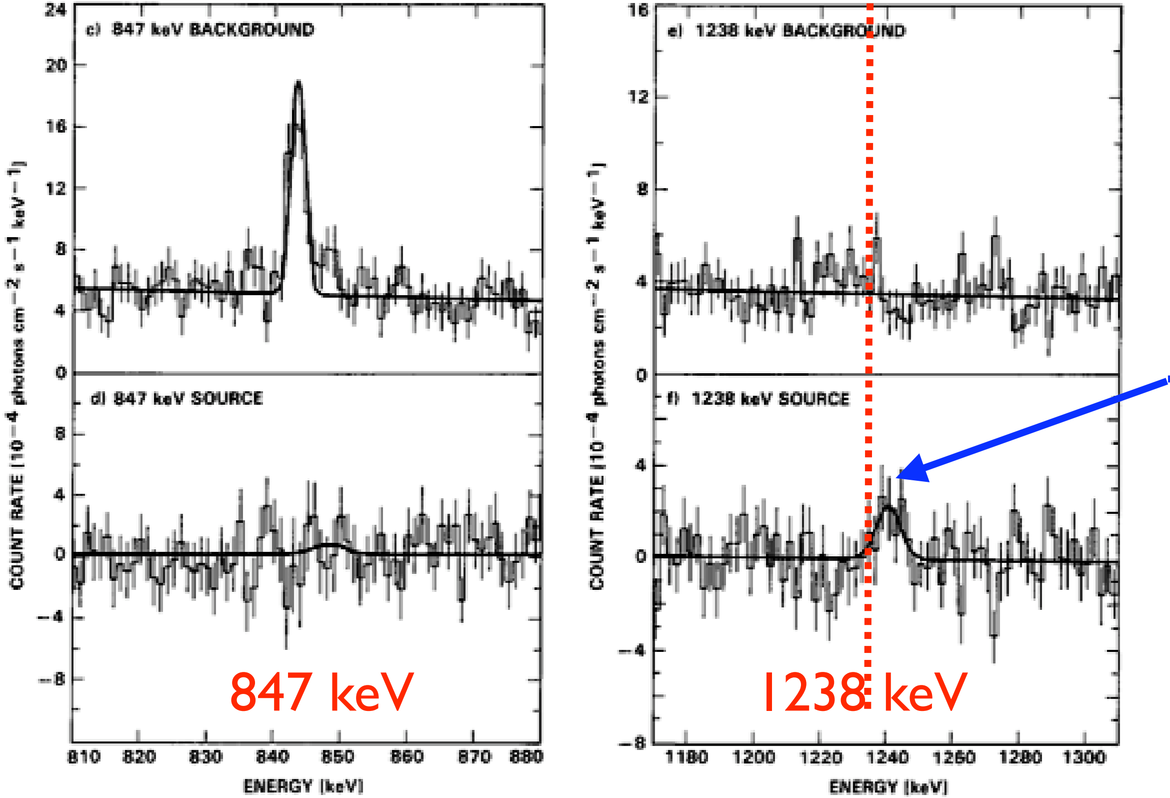


-> only a few percent of the total ~0.075 Mo of ^{56}Co was exposed, as expected

SN 1987A: ^{56}Co

Another balloon experiment, 286 d after explosion: JPL (Jet Propulsion Laboratory) high resolution spectrometer

Mahoney et al. 88



Line at 1240.8 ± 1.7 keV
(2.1±0.7) 10^{-3} ph cm^{-2} s^{-1}
- blue shifted
- intrinsic width of 8.2 ± 3.4 keV FWHM

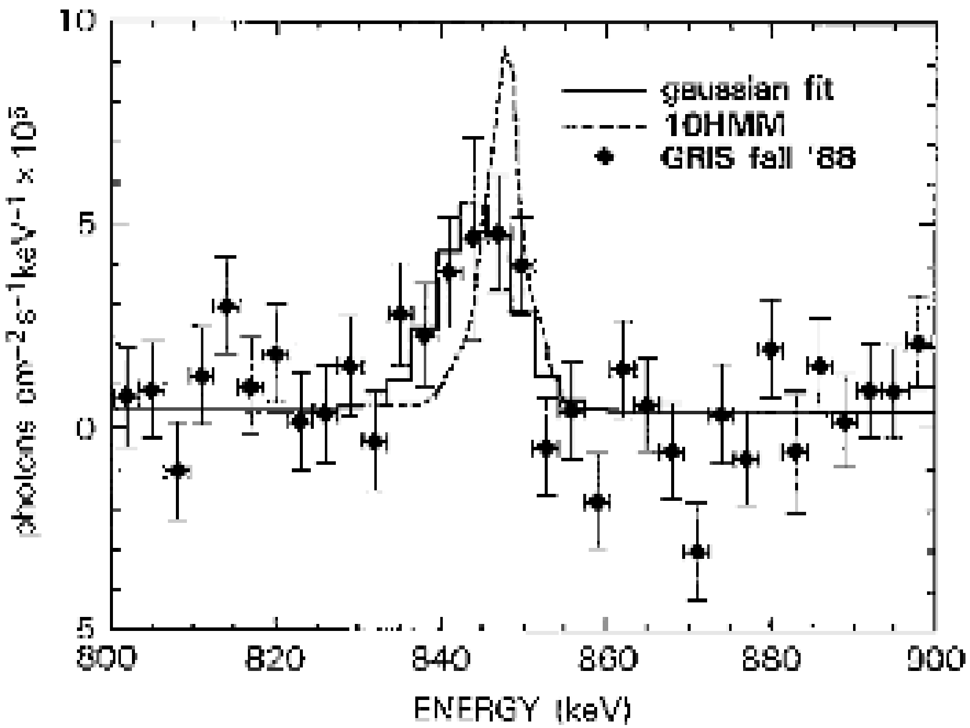
Consistent with models incorporating mixing of the Co in the expanding ejecta.

At the time of the observation, 0.0062Mo of 56Co remained from initial 0.075Mo. Flux corresponds to 5% of the 0.0062Mo.

SN 1987A: ^{56}Co

Yet another balloon experiment, largest and most sensitive instrument at the time for SN lines:
GRIS (Gamma-ray Imaging Spectrometer)

Tueller et al. 1990

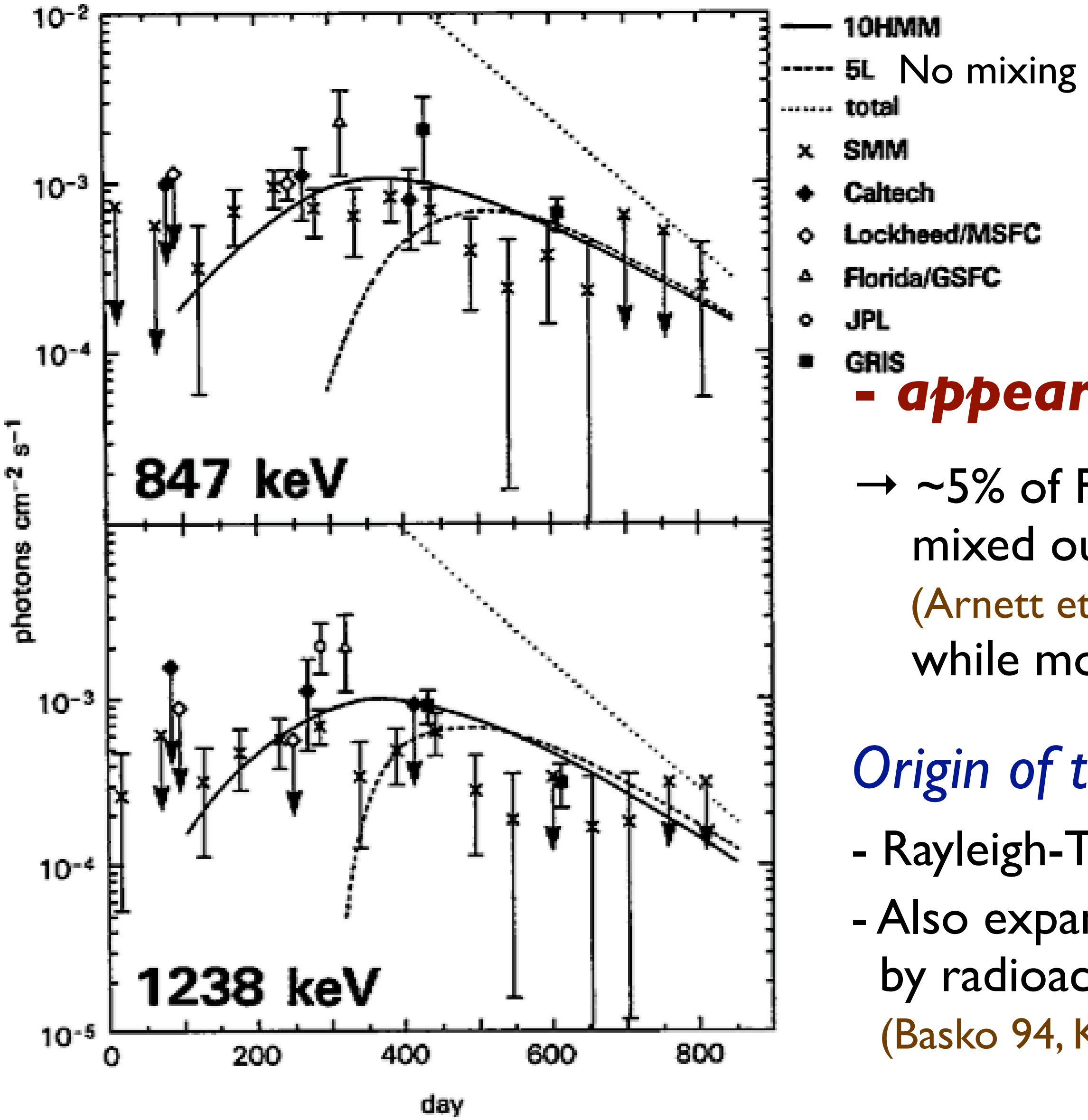


Both lines:
- ***broadened*** by ~3000 km/s
- ***redshifted*** by ~400 km/s

→ Still not understood; asymmetric explosion?
(should be blue-shifted from expanding sphere facing us, Pinto & Woosley 88)

SN 1987A: ^{56}Co

Tueller et al. 90



- appeared 6 months too early

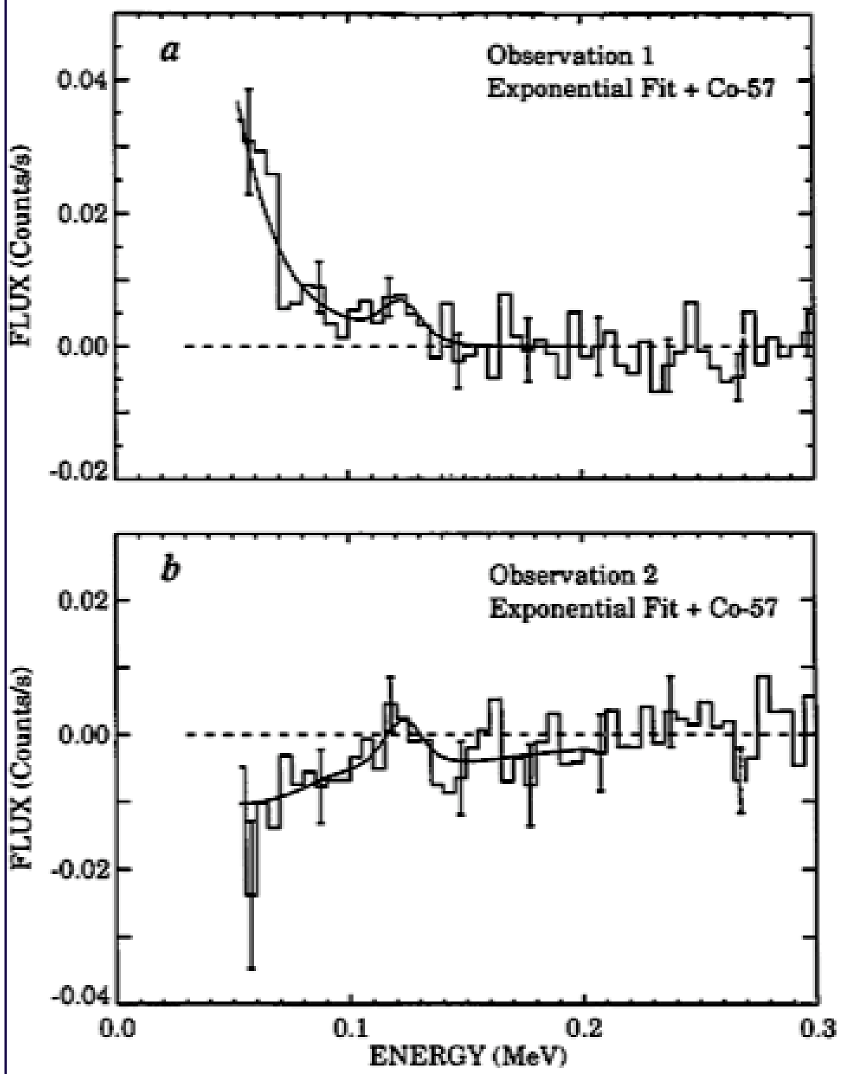
→ ~5% of Fe-group material must have mixed out to ~3000 km/s (Arnett et al. 89, Leising & Share 90), while most should have v <1000 km/s.

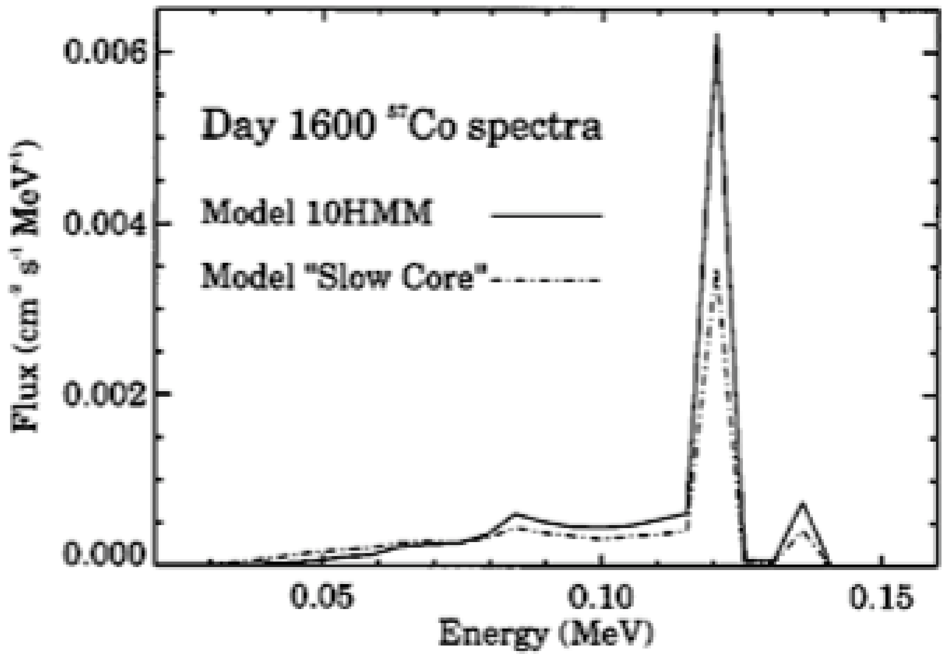
Origin of the mixing:

- Rayleigh-Taylor instabilities
- Also expansion of ^{56}Ni/^{56}Co-rich bubbles by radioactive heating (Basko 94, Kifionidis et al 03)

SN 1987A: ^{57}Co

122 keV line observed in 1992 with CGRO/OSSE





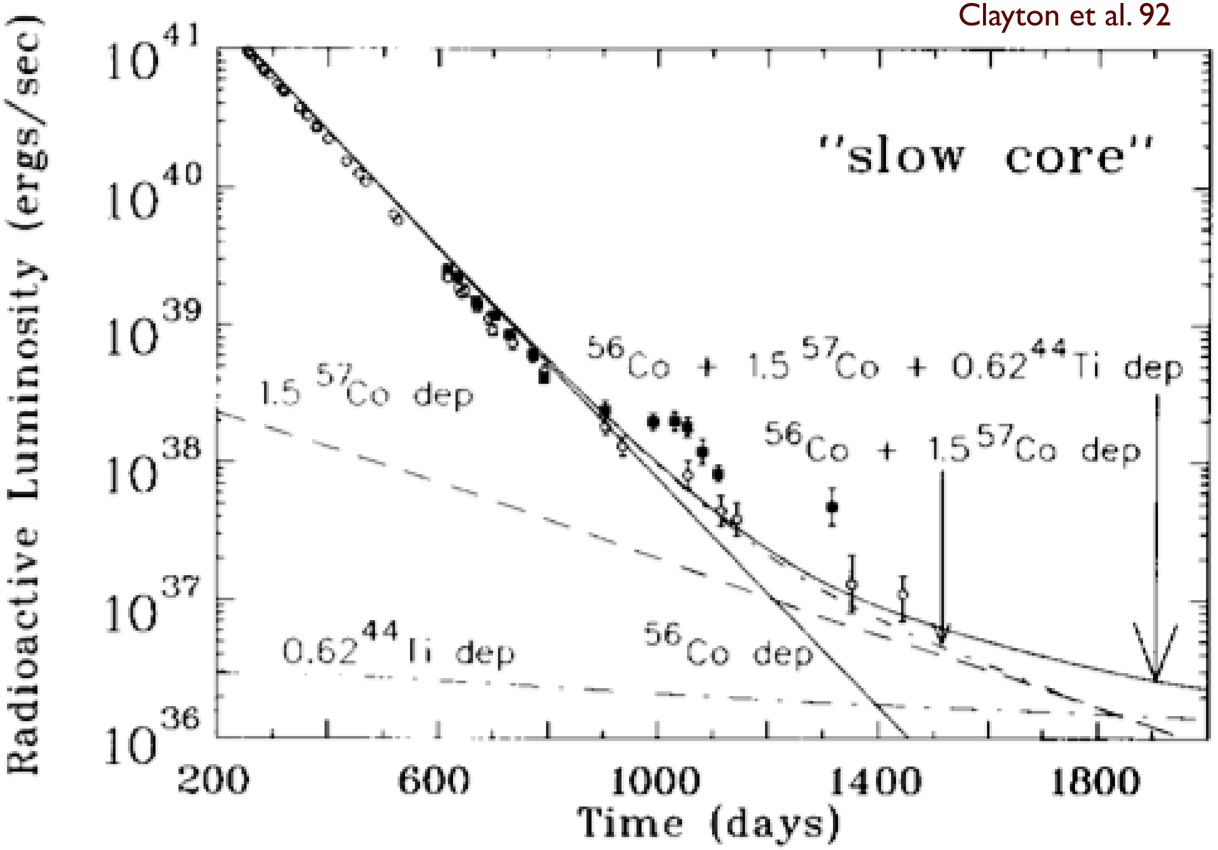
Flux ~10^{-4} ph cm^{-2} s^{-1}

→ **^{57}Ni/^{56}Ni ~ 1.5-2 x solar**

consistent with lightcurve

SN 1987A: ^{44}Ti

Clayton et al. 92

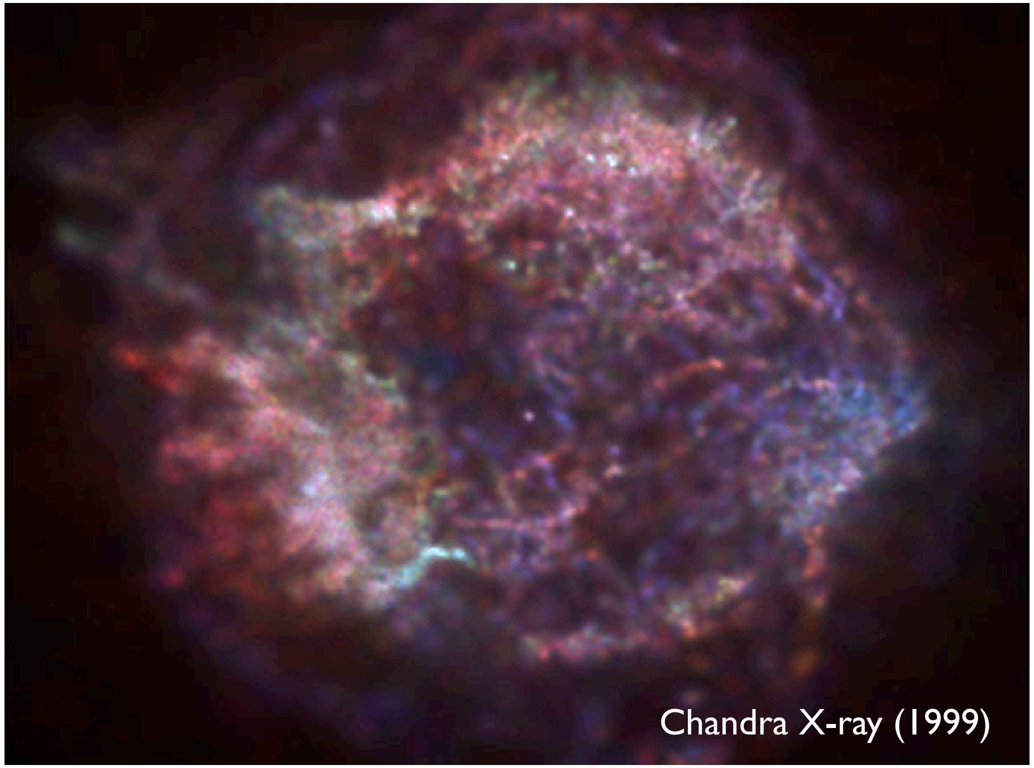


From light curve:

M(44Ti) = (0.82-2.3) x 10^{-4} M☉ (Motizuki, Kumagai 2004)

^{44}Ti too weak for current telescopes

Cas A: Generalities



- Exploded in 1667
- d ~ $3.4^{+0.3}_{-0.1}$ kpc
- Youngest known SN in MW

- Probably SN Ib with a massive WR star as progenitor

- M_{ejecta} : 10-15 $M_\odot$
  (from dynamical determination from optical and X-ray measurements)
  → $M_{progenitor}$: 20-30 $M_\odot$

- Expected ^{44}Ti yield : (2-15) x10^{-4} $M_\odot$ (Woosley & Weaver 95)
  -> below COMPTEL detection limit ?

Cas A: ^{44}Ti

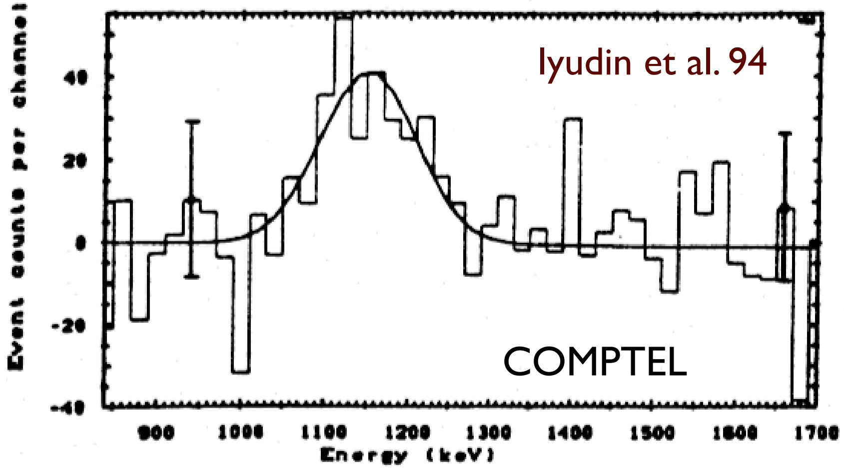
COMPTEL detection @ 1157 keV

1994

* Flux: (7.0±1.7) x 10^{-5} ph cm^{-2} s^{-1}

→ (1.4±0.4) x 10^{-4} M$\odot$ if (96.1yr, 1680)
(3.2±0.8) x 10^{-4} M$\odot$ if (78.2yr, 1667)

* Width: -> 11000±3100 km/s
(mean exp. velocity for SNR shell: 5300-6800 km/s)

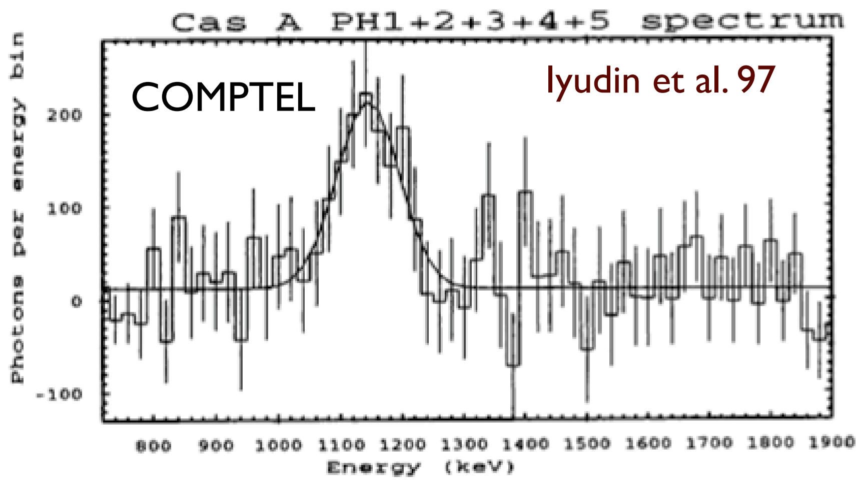


1997

* Flux: (4.8±0.9) x 10^{-5} ph cm^{-2} s^{-1}

→ (1.30±0.25) x 10^{-4} M$\odot$ if (96.1yr, 1680)
(3.30±0.63) x 10^{-4} M$\odot$ if (78.2yr, 1667)

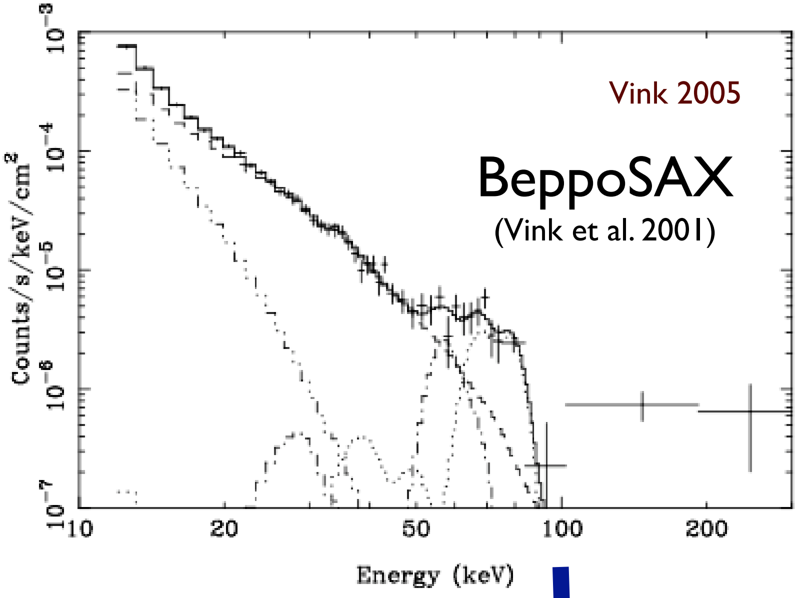
* Broadening: -> 7200±2900 km/s

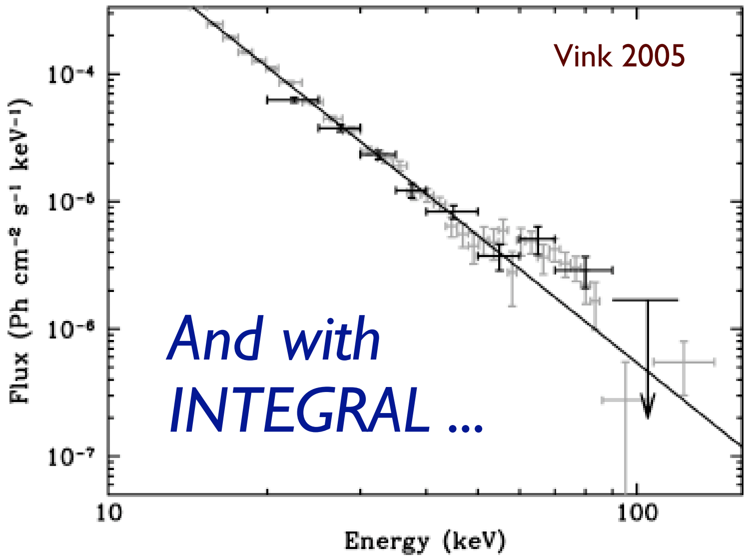


2000: (3.4±0.9) x 10^{-5} ph cm^{-2} s^{-1}

Cas A: ^{44}Ti

Detection of the **67.9 and 78.4 keV** lines with BeppoSAX





But continuum makes line measurement difficult

Flux: $(1.9\pm0.4) \times 10^{-5}$ ph cm^{-2} s^{-1} if powerlaw continuum

$(3.2\pm0.3) \times 10^{-5}$ ph cm^{-2} s^{-1} if steepening of synchrotron and non-thermal bremsstrahlung

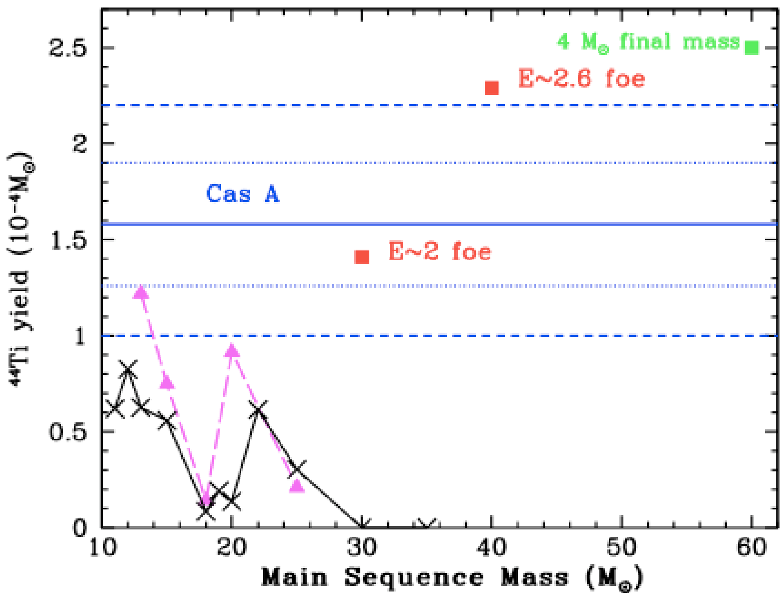
COMPTEL+BeppoSAX averaged results:

$(2.6\pm0.4\pm0.5) \times 10^{-5}$ ph cm^{-2} s^{-1}

statistical error — systematic error due to bkg

Vink 2005

Cas A: ^{44}Ti



* New mearurements of ^{44}Ti life time

86.0±0.5 y (1998-1999)

→ M(^{44}Ti) = (1.6±0.3±0.3) x 10^{-4} Mo

Similar to that from SN 1987A

Model predictions too low !

Why ? (cf.Vink 05)

More energetic ?	Kinetic energy derived from SNR's kinematic ~2x10^{51} erg (Laming & Hwang 2003)
Asymmetric SN ?	Ample evidence of asymmetryc ejecta expansion (e.g. Hwang et al. 2004)
Higher pre-SN mass loss?	Ejecta mass measered in X-rays quite low, 2-4 Mo
Uncertain yields ?	1-D models, no rotation, no magnetic field, ...

Higher effective ^{44}Ti life-time ? (If ionized, EC rate drops, Mochizuki et al. 1999, Motizuki & Kumagai 2004)

But X-ray spectroscopy indicates that both Ca and Fe (similar ionization cross sections) are still ionizing

SN 1991T, SN 1998b : ^{56}Co

SN 1998b: SN Ia in NGC 4527 (9-17 Mpc)

* CGRO/COMPTEL (Lichti etal. 94) and CGRO/OSSE (Leising etal. 95)

→ upper limit on ^{56}Co: (3-4) x 10^{-5} ph cm^{-2} s^{-1}

Rem: predicted flux close to those upper limits

* Re-analysis (Morris et al. 97):

→ M(^{56}Ni) ~ 2Mo (3σ detection)

in agreement with predictions (but low signal to noise ration of 10^{-4}!)

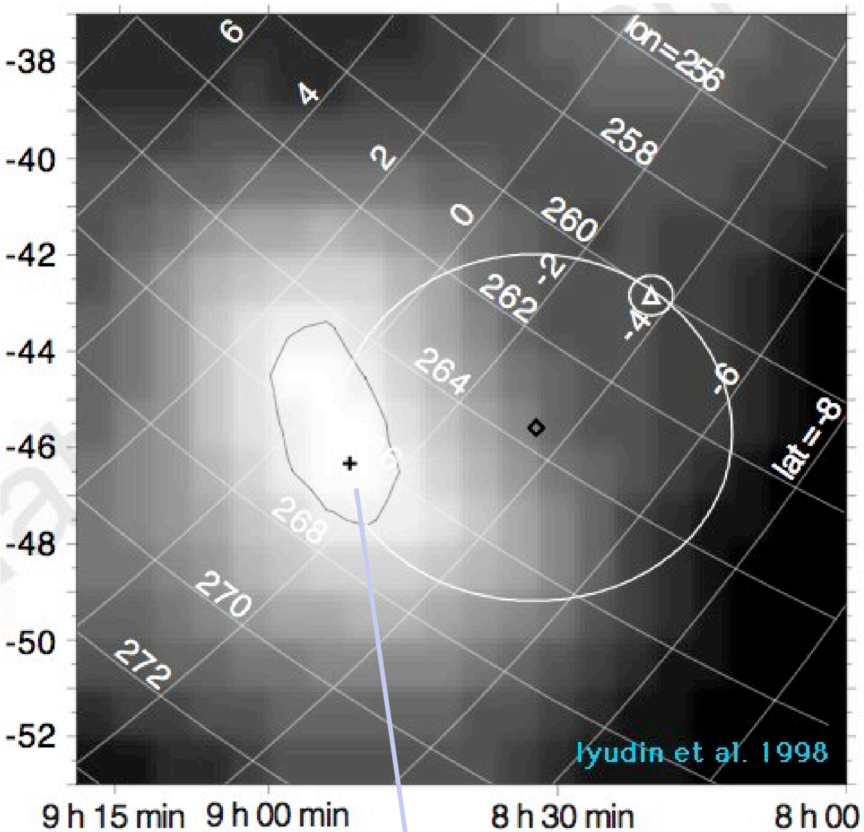
SN 1998b: SNIa in M96 (11.3±0.9 Mpc)

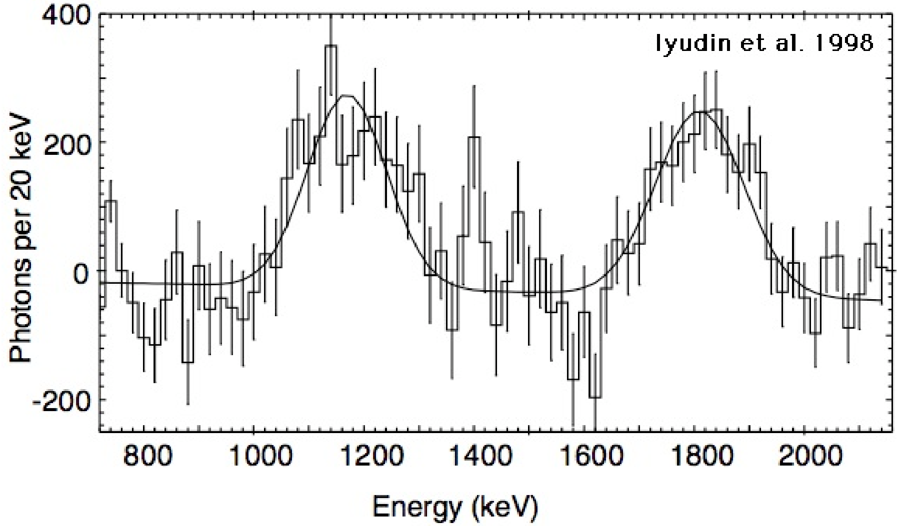
No ^{56}Co detection!

Vela JR: ^{44}Ti

1.157 MeV emission by *COMPTEL*

(Iyudin et al. 1998, Nature 396, 142)





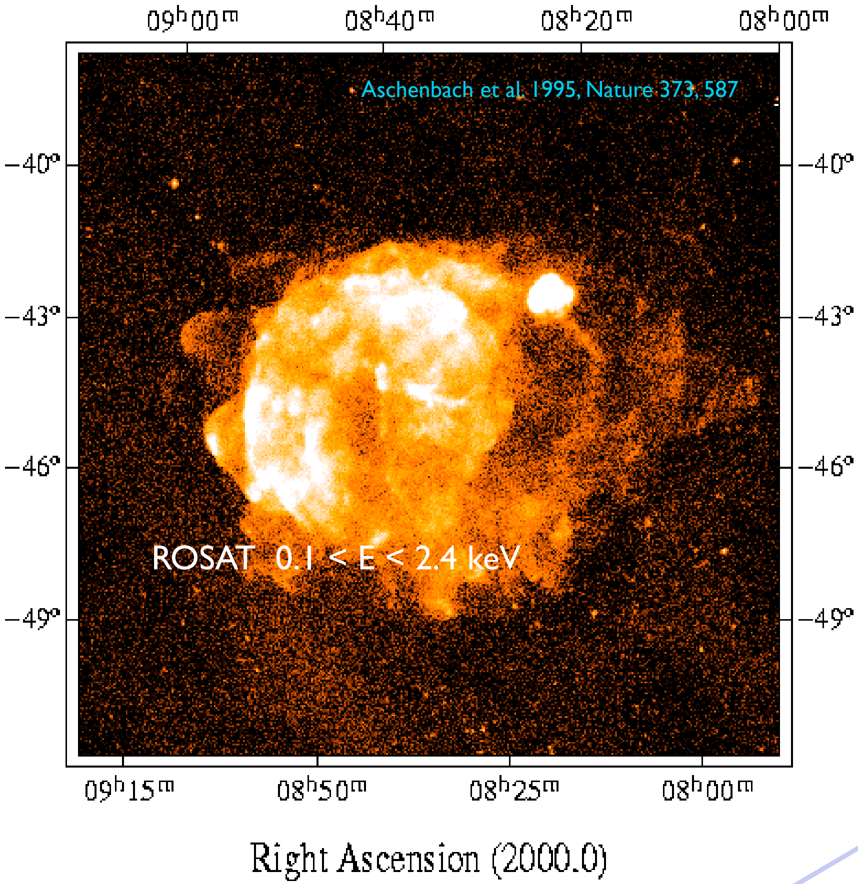
GRO J0852-4642

$^{44}f = (3.8 \pm 0.7) \times 10^{-5}$ ph cm^{-2} s^{-1}

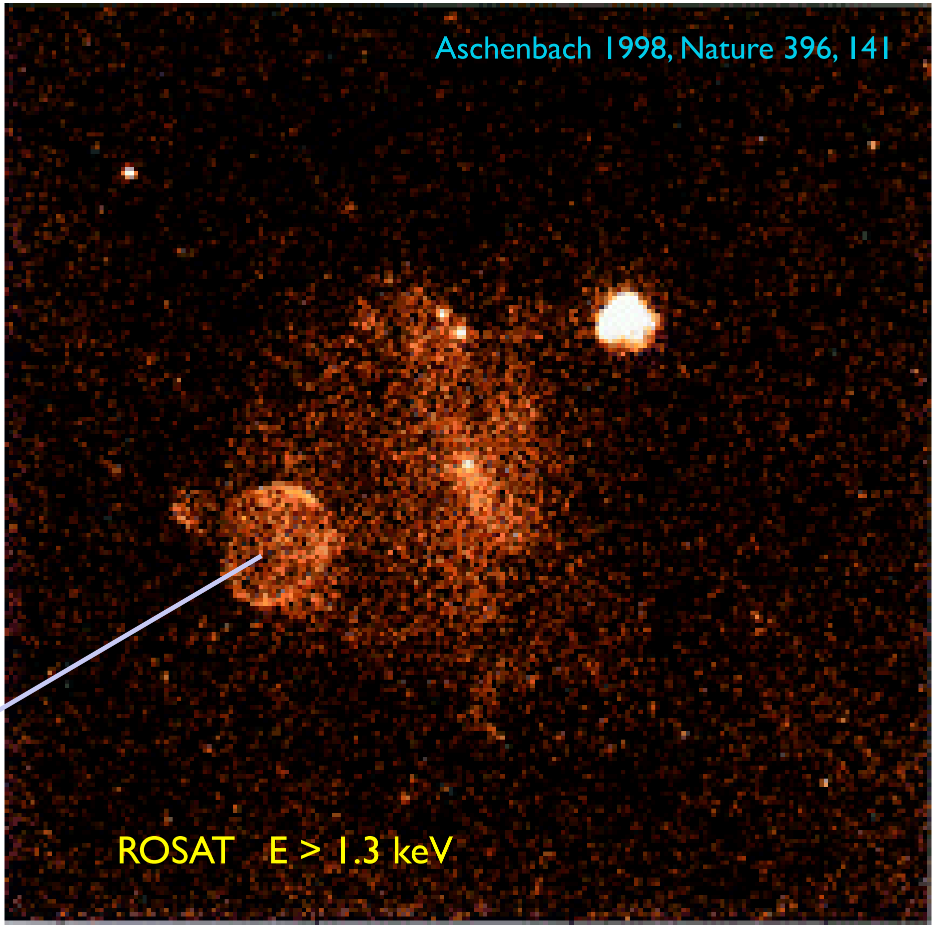
If 5000 km s^{-1} and M(^{44}Ti)=5x10^{-5} M$_\odot$

-> t~680 y and d~200pc

Vela JR: ^{44}Ti



Discovered in the *ROSAT* all-sky survey

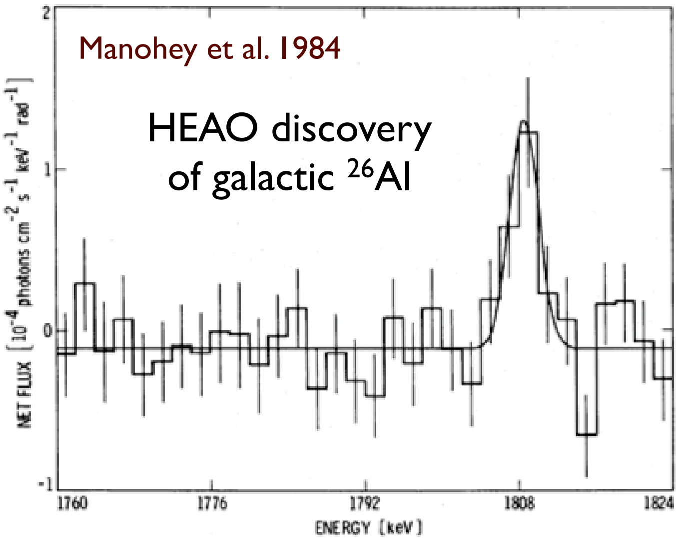


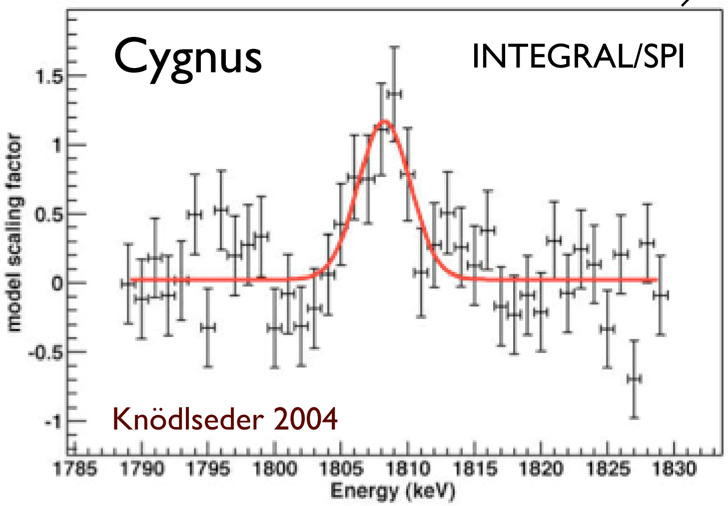
RX J0852.0-4622

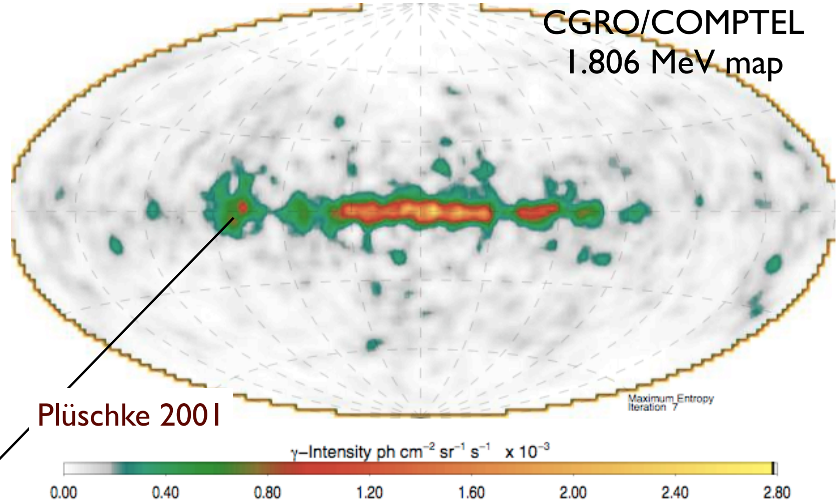
X-ray spectra: $T>3\times10^7$K -> young object

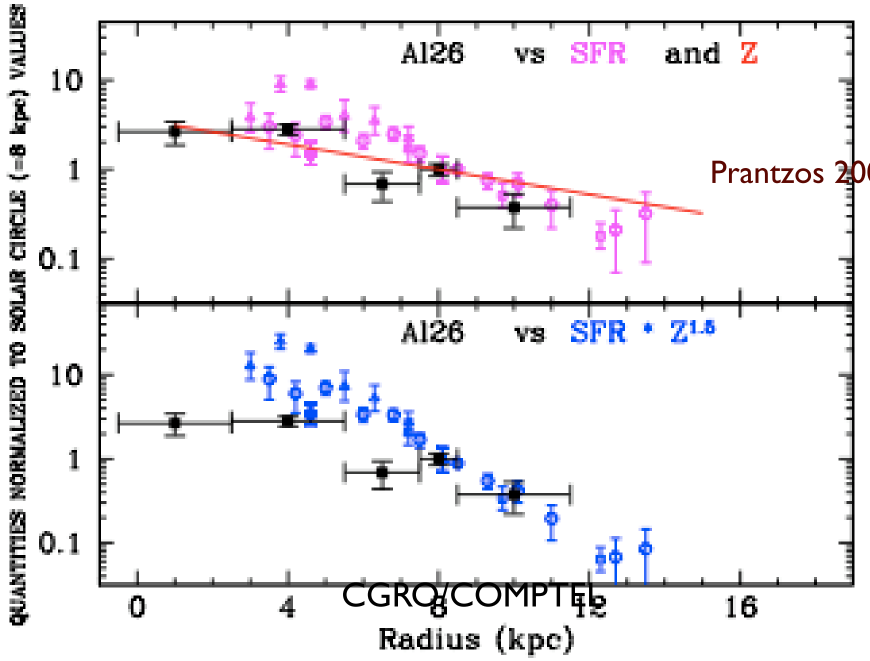
Galactic ^{26}Al diffuse emission

2-3 Mo of live ^{26}Al in the Galaxy



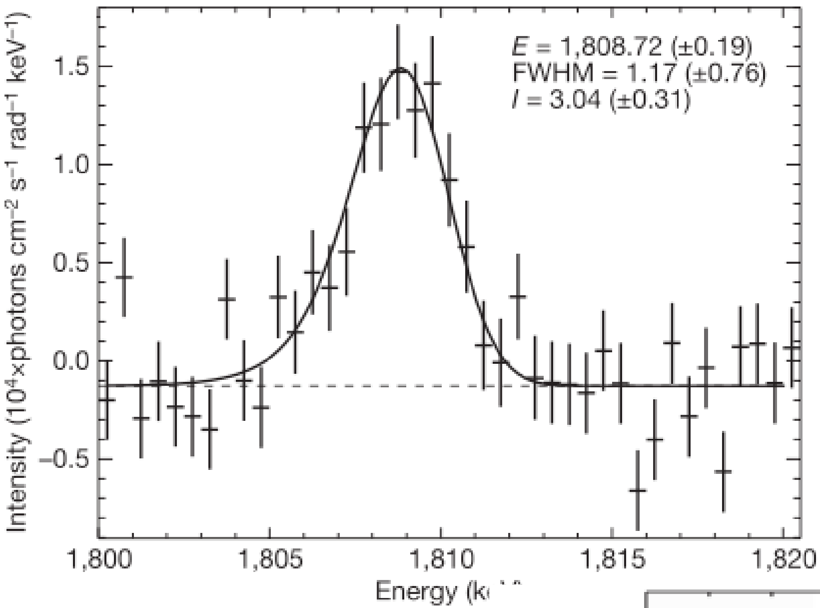






Galactic ^{26}Al diffuse emission

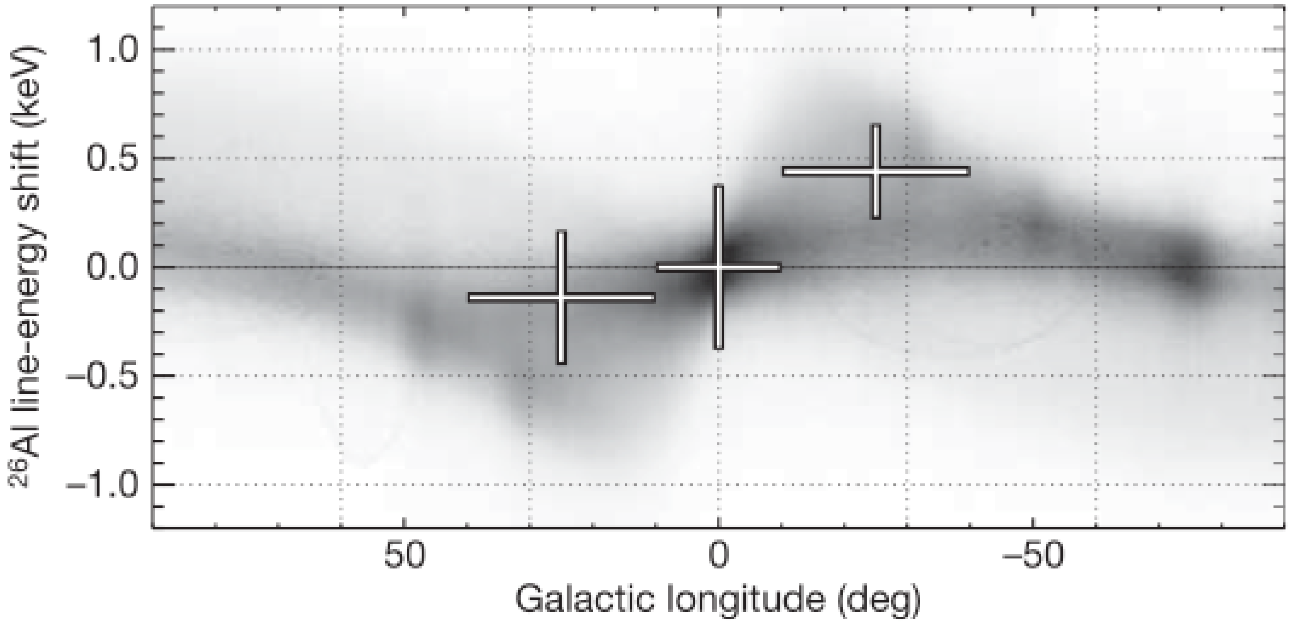
Diehl et al. 2006



INTEGRAL/SPI
1.5 years of data
-> (2.8±0.8) Mo of ^{26}Al

Diehl et al. 2006

Galactic rotation
(v~200km/s)



Binary system in Vela region:

l = 262.80°
b = -7.69°
d = 258 (+41,-31) pc

(Schaerer et al. 1997)

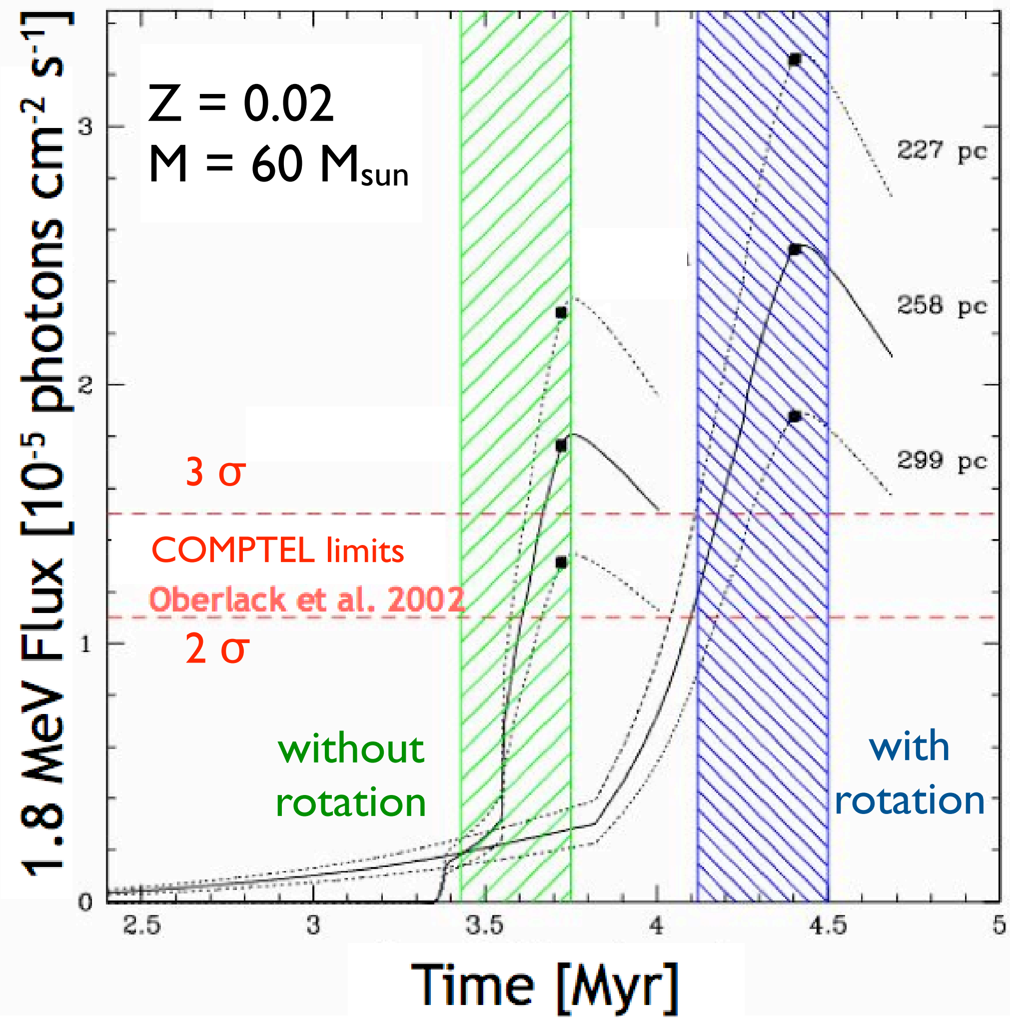
- Main sequence **O7** star
  M_O = 30 ± 2 Mo

- WR star of type **WC8**
  M_{WR} = 9 $^{+2.5}_{-1.2}$ Mo

(Schmutz et al. 1997)

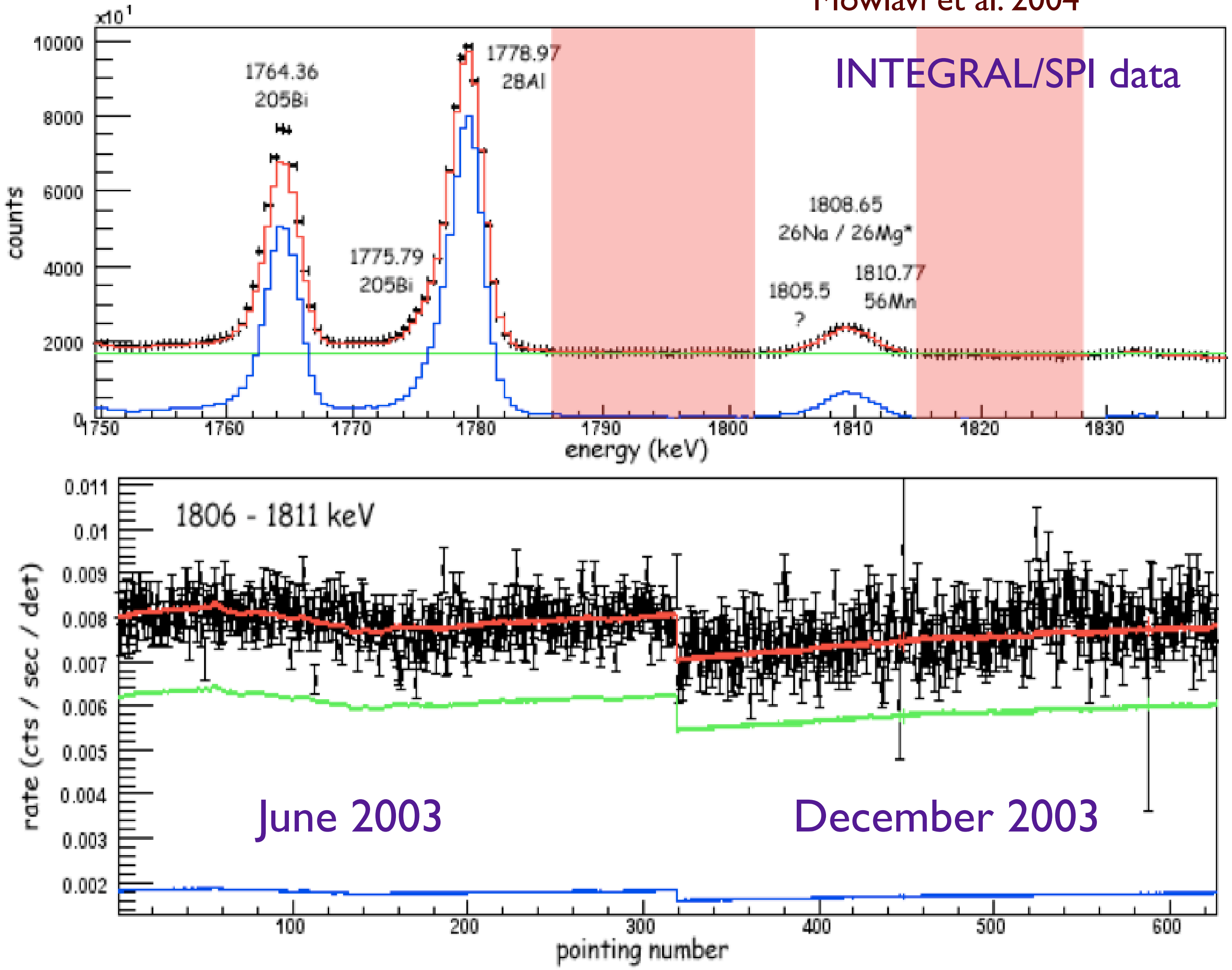
Why not detected by COMPTEL ?

Mowlavi et al. 2005



γ²-Velorum: ^{26}Al

Mowlavi et al. 2004



COMPTEL (9 years) upper limit not reached after 1 year of INTEGRAL

γ^2-Velorum: not a point source in 1.8 MeV ?

Assume bubble around WR11 ....

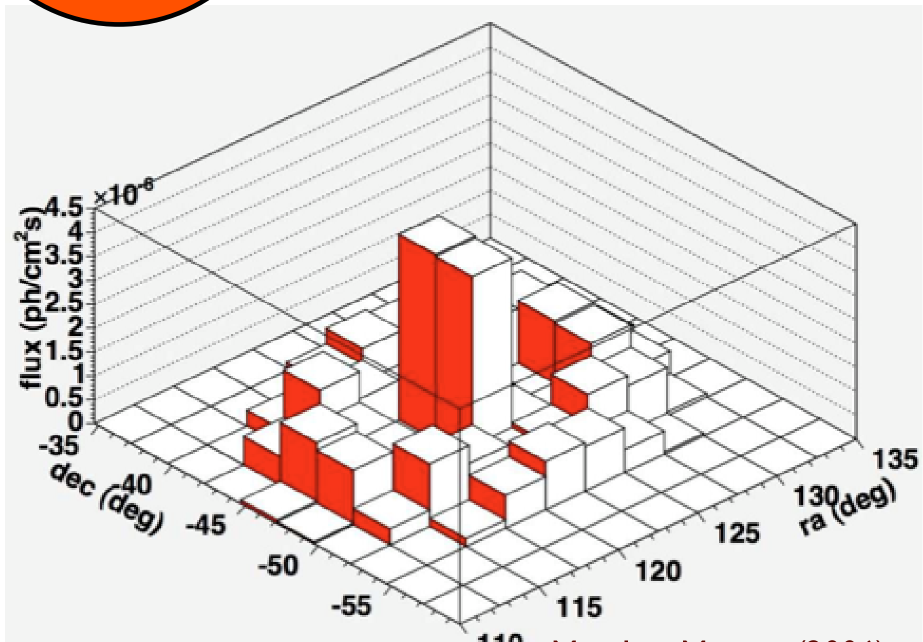
WR11 @ 260 pc

model : 60 M$_\odot$, Z=0.02,
$v_{rot,init}$=300 km/s

(age=4.3 Myr)

→ ^{26}Xs(t), $\dot{M}$(t)

... and integrate expected 1.8 MeV flux for SPI →

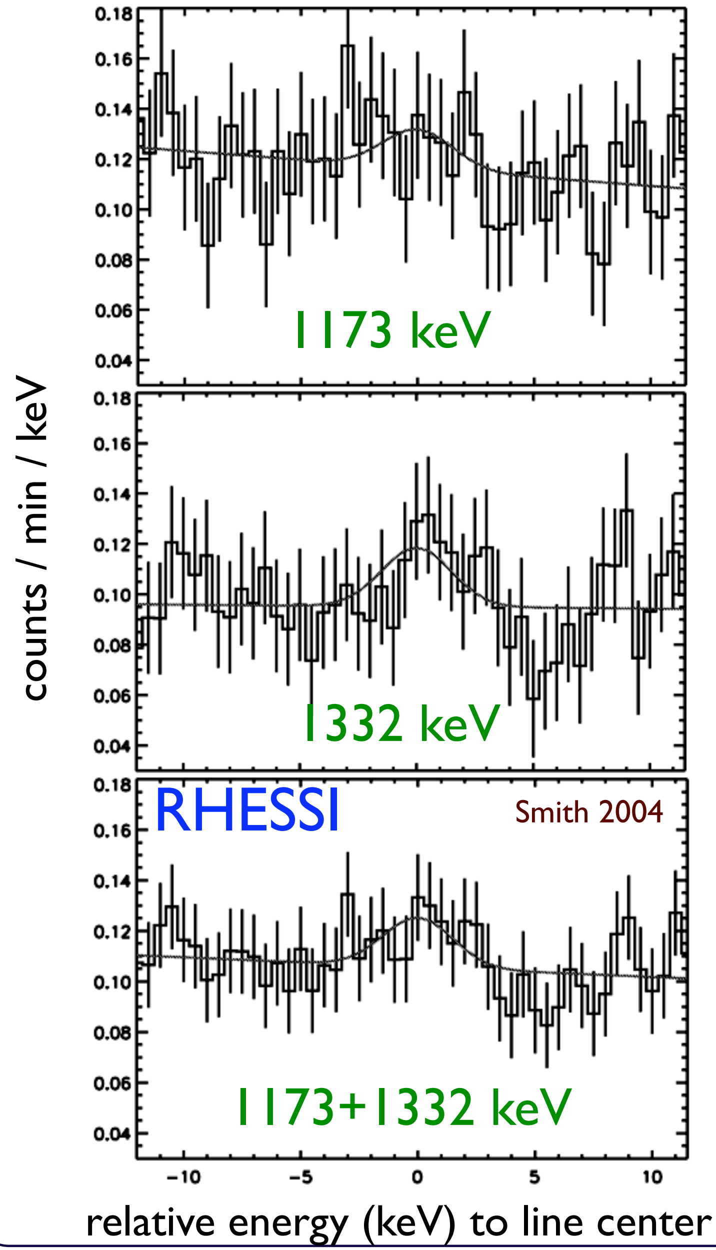


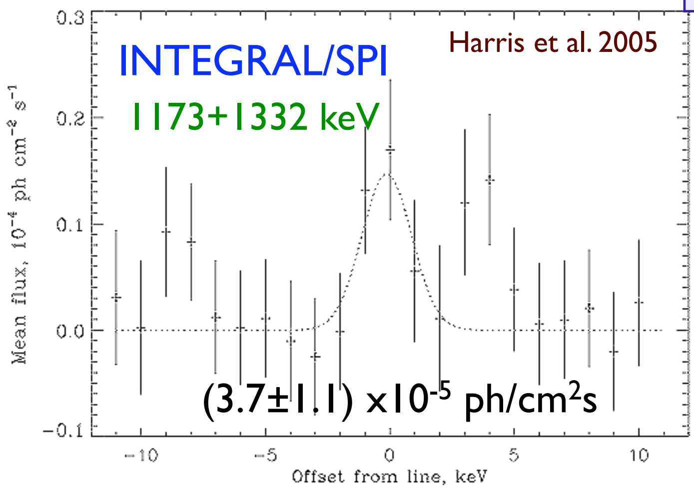
Mowlavi, Meynet (2006)

→ ***Would be compatible with non-detection***

or, simply, further away than assumed?

Galactic ^{60}Fe

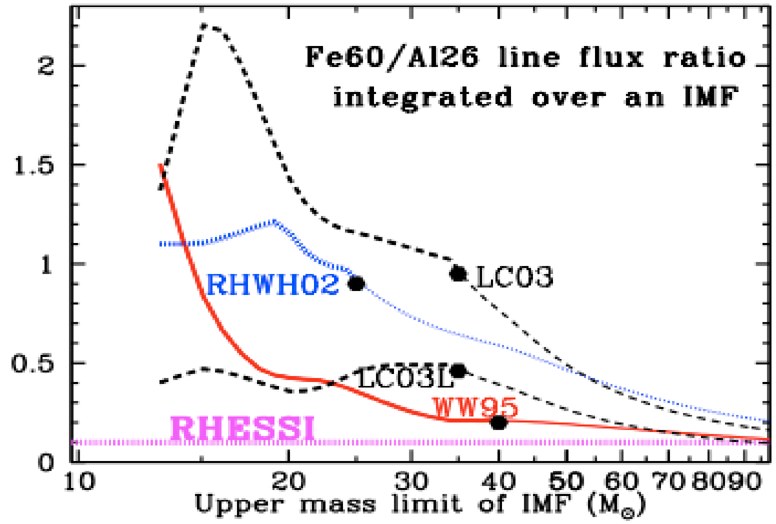




↳ **^{60}Fe/^{26}Al = 0.11 ± 0.03**

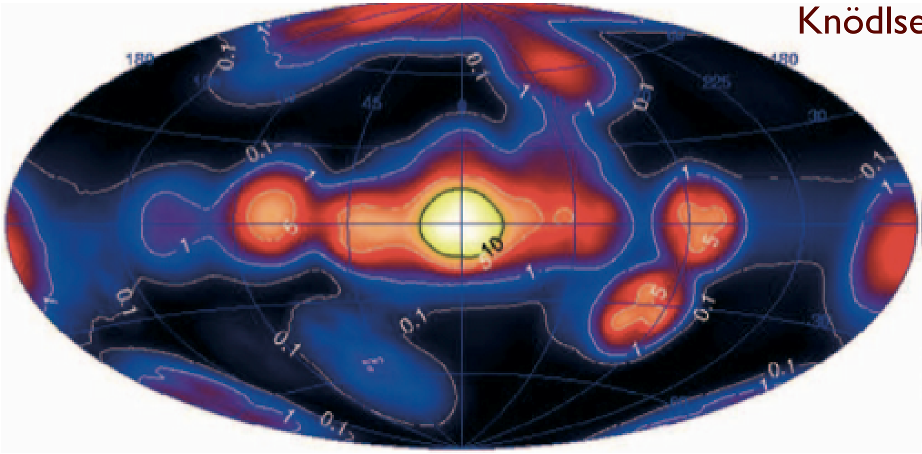
Needs extra source of 26Al other than core collapse SN

Prantzos 2004

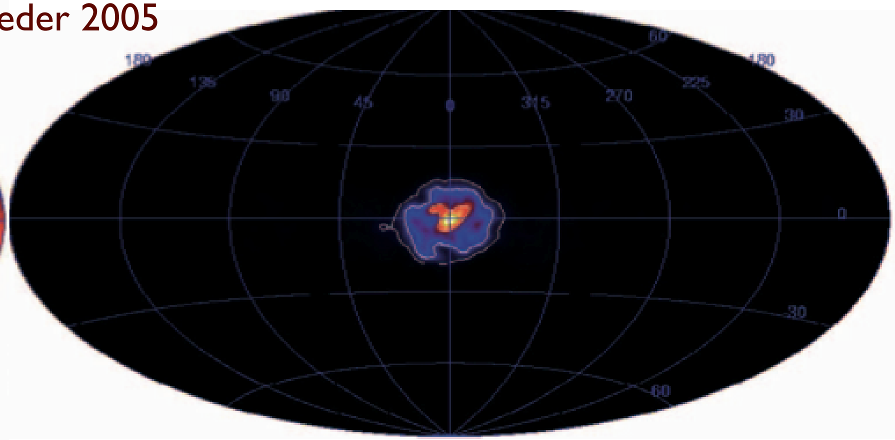


INTEGRAL/SPI

Knödlseder 2005



Effective exposure map



511 keV map

* Weak detection in disk
  - $(0.3\pm0.2)\times10^{43}\ s^{-1}$ $(\sim4\sigma)$

← from β^+-decay of ^{26}Al and ^{44}Ti

* Strong detection in Bulge
  - $(1.5\pm0.1)\times10^{43}\ s^{-1}$ $(\sim50\sigma)$
  - highly symmetric

← SNIa and/or LMXBs in bulge ?
... or from e+ emitted by SNIa in disk and transported to bulge via galactic magnetic field (Prantzos 2006)

Conclusions

* Very **few objects**
* But **very valuable** because direct comparaison with model predictions.