Gamma-ray observations from ^{60}Fe decay in the Galaxy

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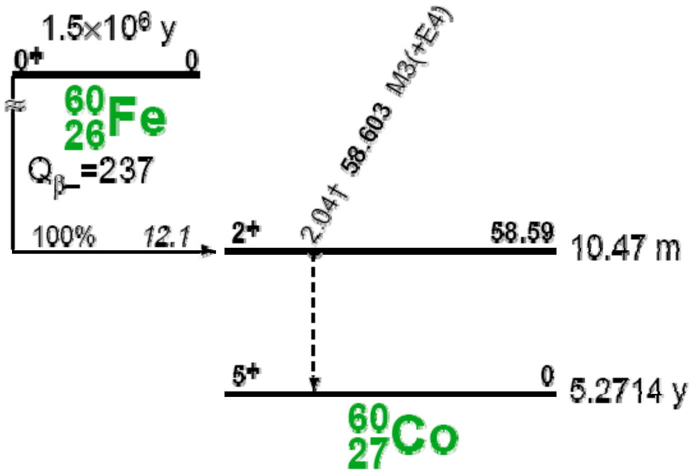
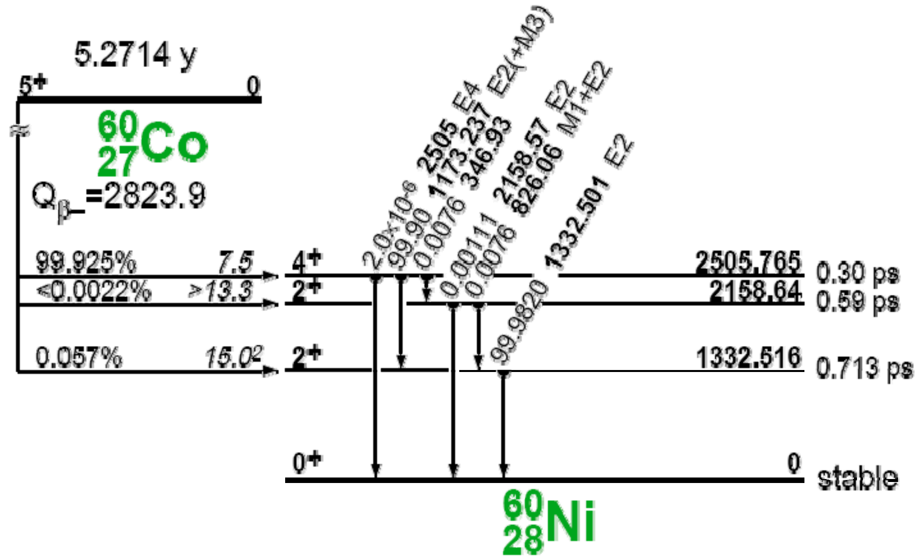
MPE

^{60}Fe Decay

$T_{1/2}$:	1.5 My
Photons:	58.6 keV (2%)
	1173 keV
	1333 keV





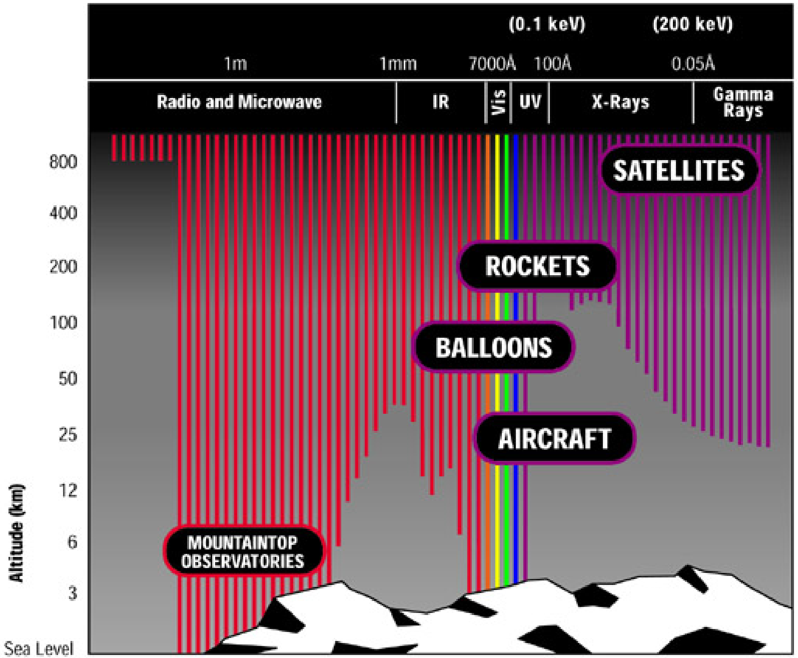
Ni59 7.6E+4 y 3/2- EC	Ni60 0+ 26.223	Ni61 3/2- * 1.140	Ni62 0+ 3.634	Ni63 100.1 y 1/2- β-
Co58 70.82 d 2+ * EC	Co59 7/2- * 100	Co60 5.2714 y 5+ *	Co61 1.650 h 7/2- β-	Co62 1.50 m 2+ * β-
Fe57 1/2- * 2.2	Fe58 0+ * 0.28	Fe59 44.503 d 3/2- β-	Fe60 1.5E+6 y 0+ β-	Fe61 5.98 m 3/2-,5/2- β-

Observations of Extragalactic ^{60}Fe

- Absorption of gamma-rays in the earth's atmosphere

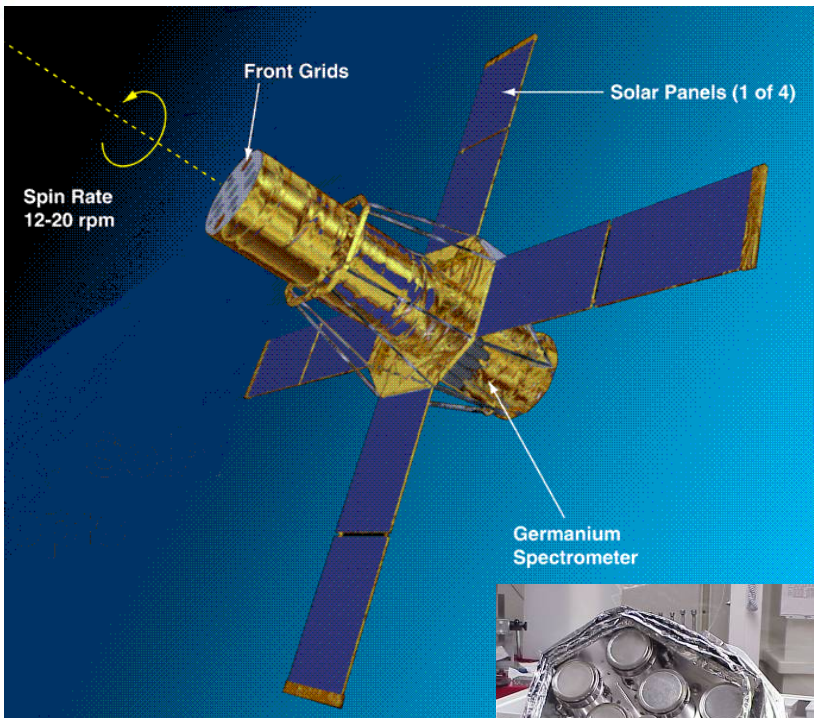
  → *Space missions*

- Reports on ^{60}Fe
  - HEAO-3 (1982)
  - SMM (1994)
  - CGRO (1997) (OSSE & COMPTEL)
  - GRIS (1998) < 2 σ
  - RHESSI (2004) 2.6 σ
  - INTEGRAL (2005/7) > 3 σ

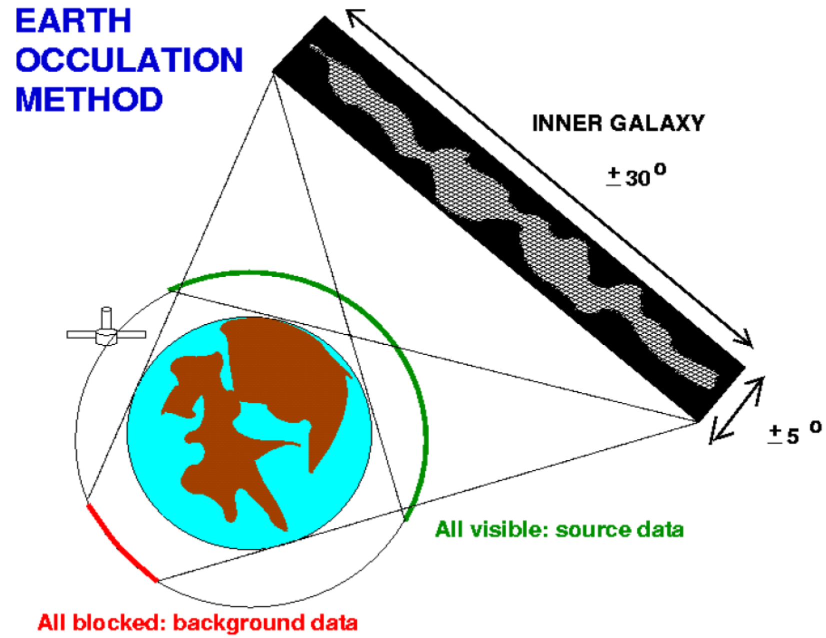


chandra.harvard.edu

Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)



hesperia.gsfc.nasa.gov

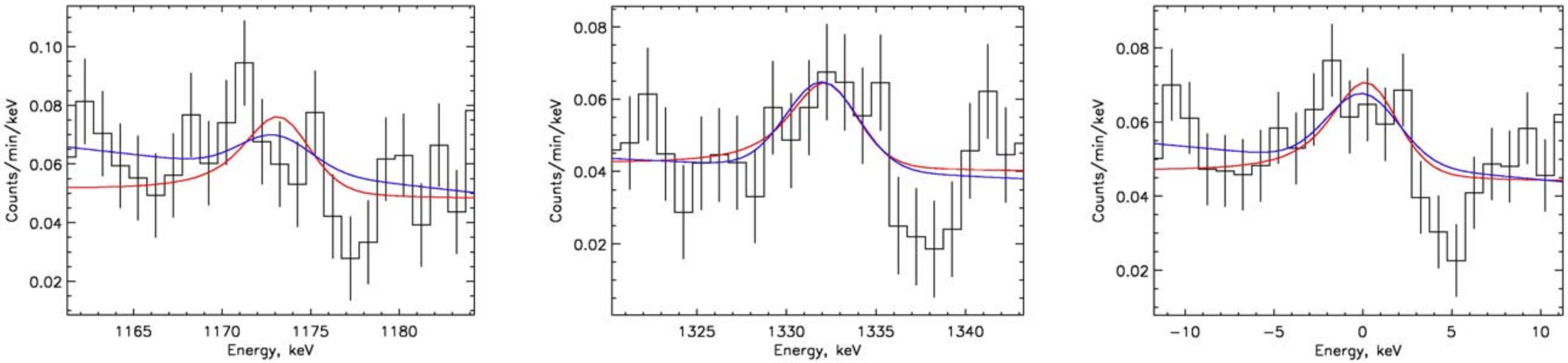


From Smith (AwR V, 2005)

- Unshielded
- Low earth orbit

^{60}Fe Detection – Past (2005)

RHESSI (Smith) 1173 keV | 1333 keV | Combined spectrum



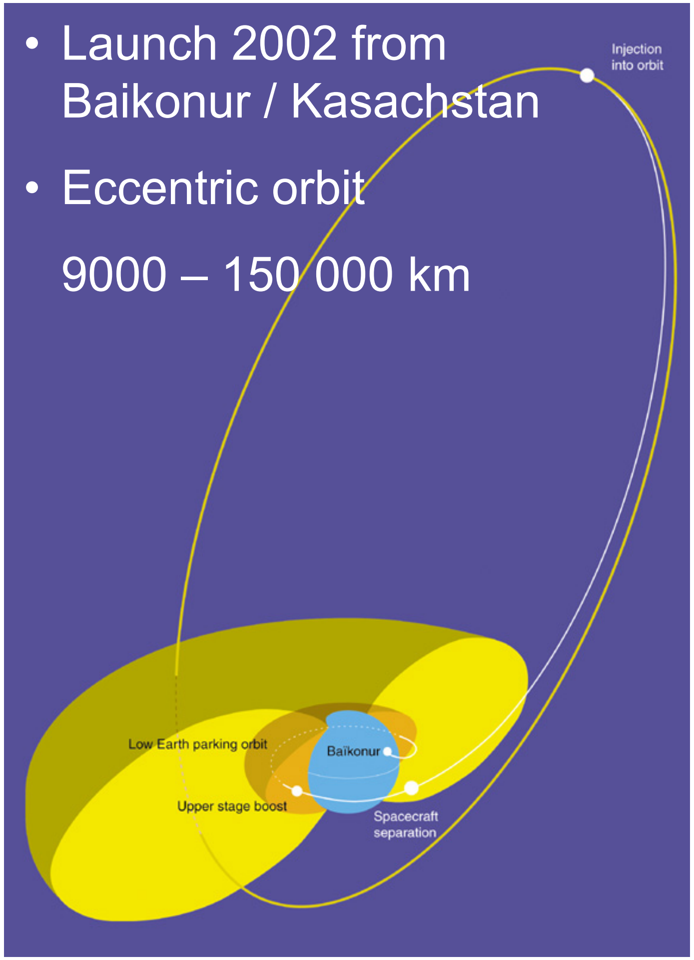
Flux [10^{-5} ph cm^{-2} s^{-1}] (σ)

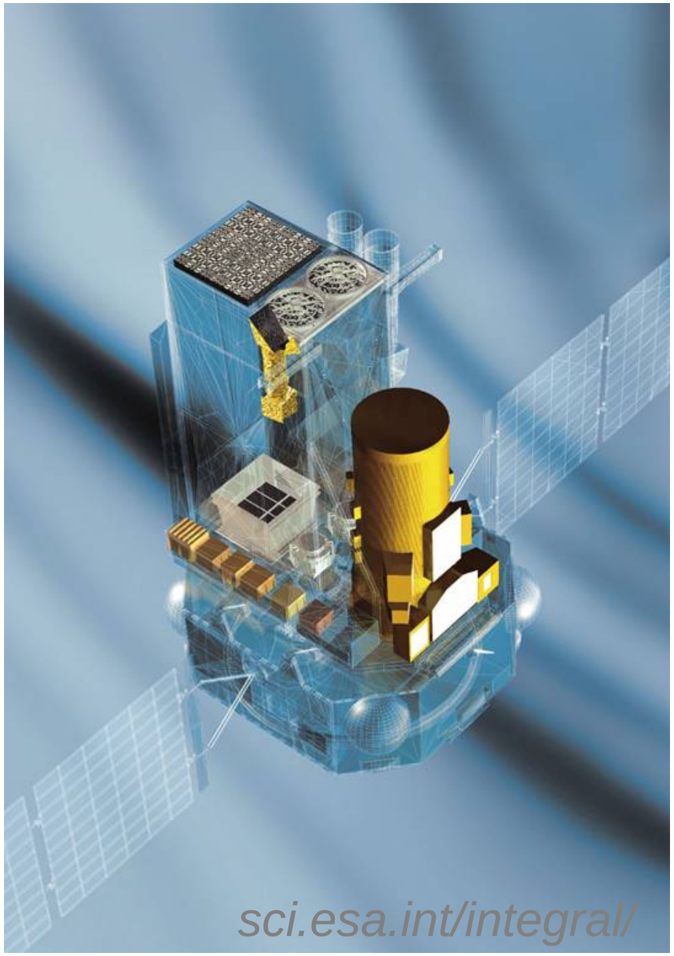
	1173 keV	1333 keV	Combined
Old method	2.9 (1.5)	5.9 (3.4)	4.6 (3.7)
New method	6.5 (3.5)	5.8 (3.4)	6.3 (5.0)

International Gamma-Ray Astrophysics Laboratory (INTEGRAL)

- Launch 2002 from Baikonur / Kasachstan
- Eccentric orbit

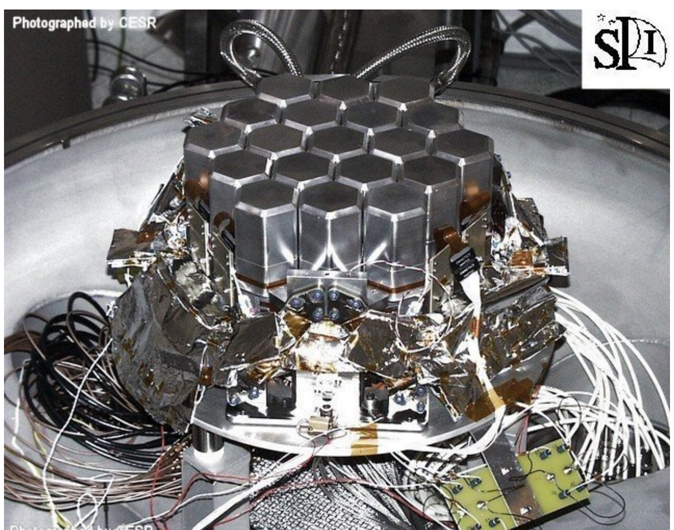
  9000 – 150 000 km

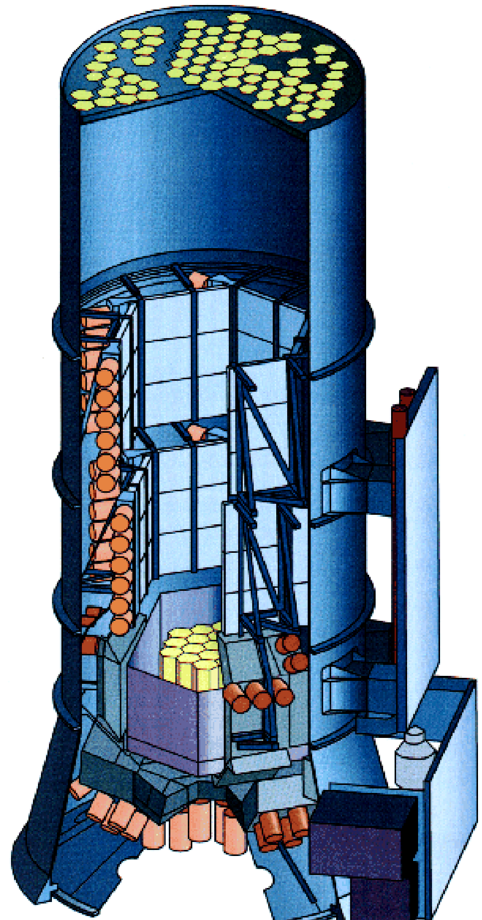




Spectrometer on INTEGRAL (SPI)

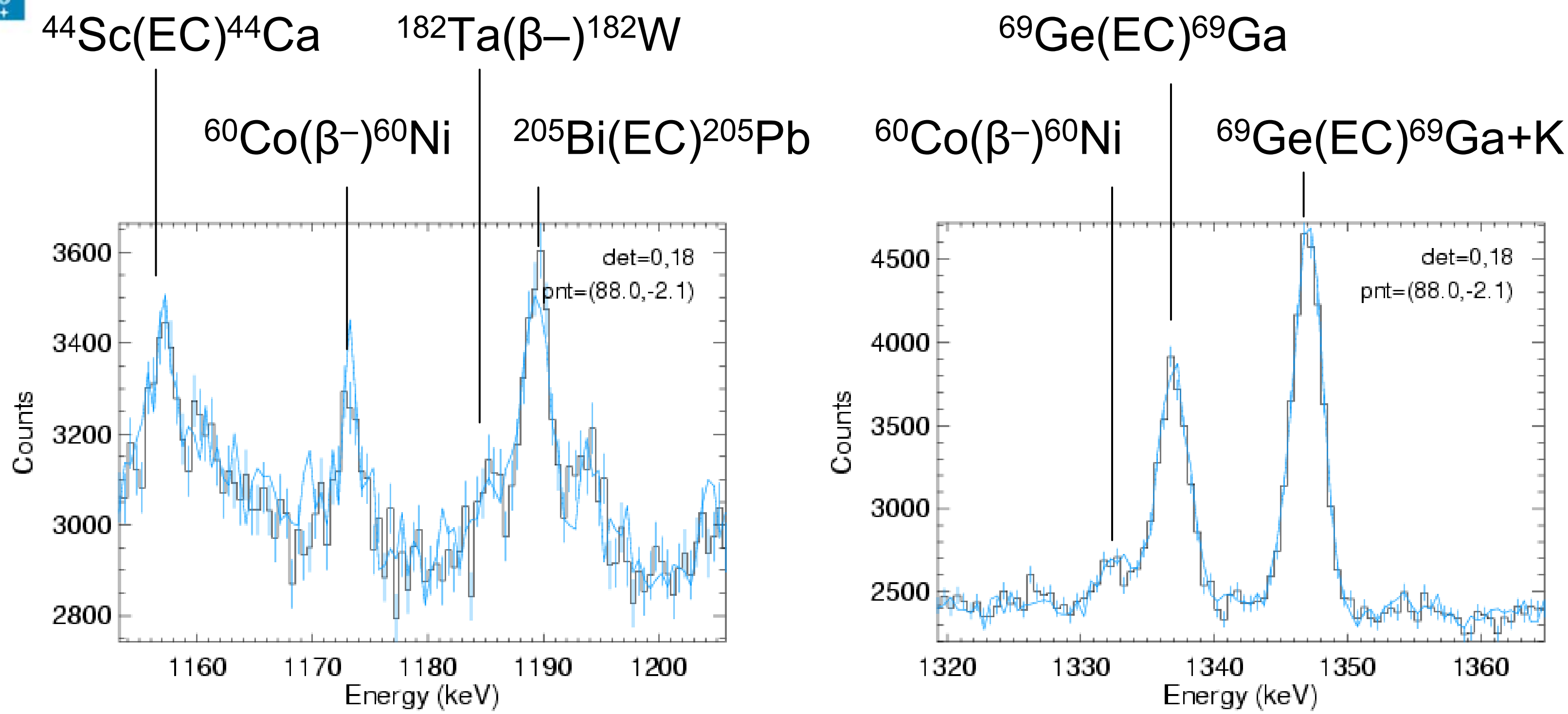
- 19 cooled Ge detectors
- 18 keV – 8 MeV
- E/ΔE ≈ 500 @ 1.3 MeV
- 16° fully coded FoV with 2° imaging resolution





sci.esa.int/integral/

SPI Instrument Spectra



(From Wang 2007, Line identification Weidenspointner, 2003)

Spectral Modelling

Spectral components:

1. GEDSAT: Prompt emission
2. GEDSAT ⊗ 7.6 y: ^{60}Co build-up
3. Expected time series from sky signal

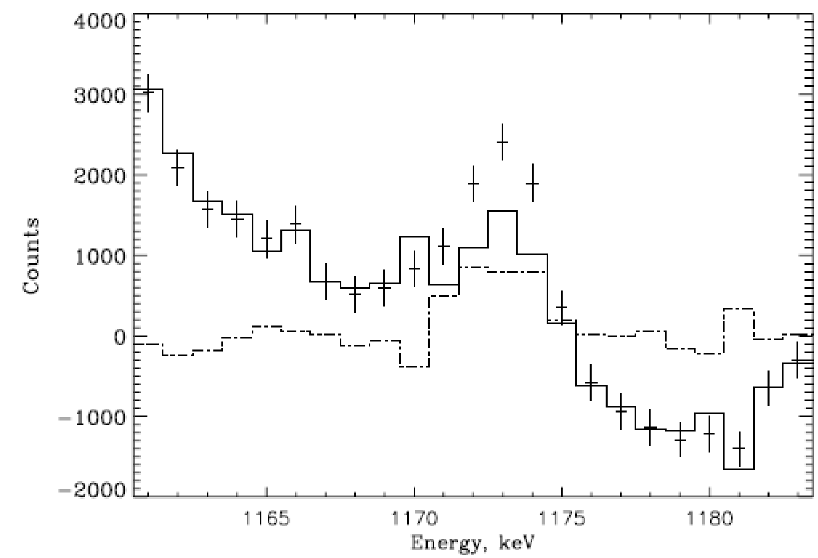
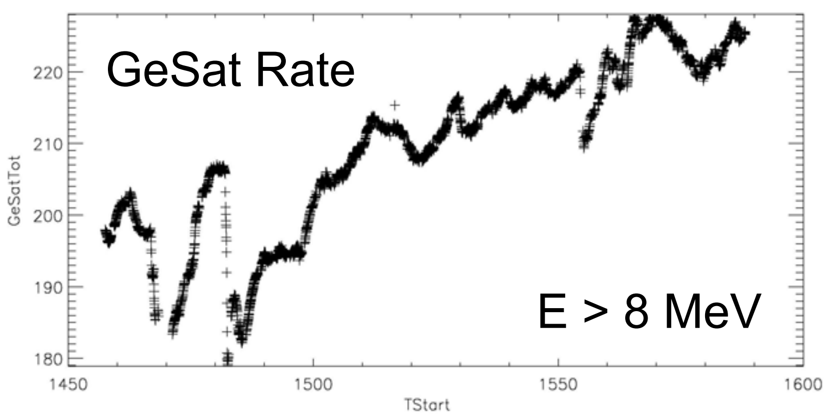
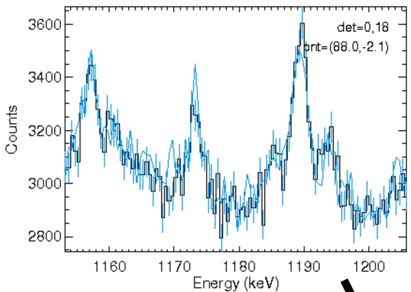


Fig. 1. Amplitudes of the GEDSAT background term (full line) and the GEDSAT ⊗ 7.6 yr background term (dot-dash line) fitted (along with the ^{60}Fe map exposure) to the time series of SE count rates for 1161–1184 keV. Data points – background counts in 1 keV bins with flat continuum subtracted.

(Harris 2005)

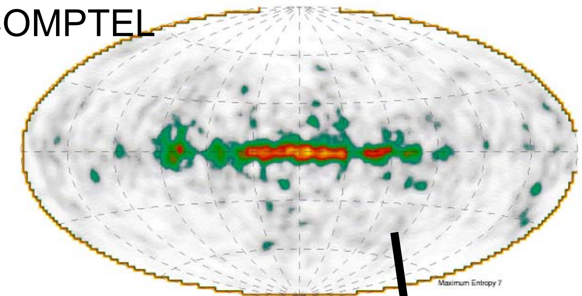


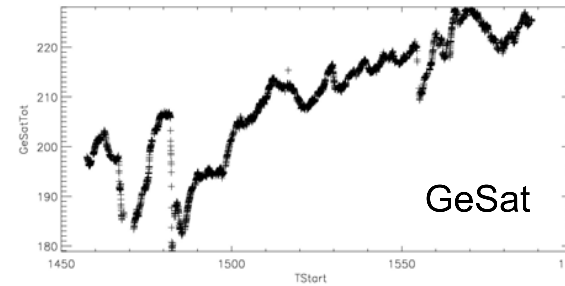
^{60}Fe Detection – Method



SPI Data

COMPTEL

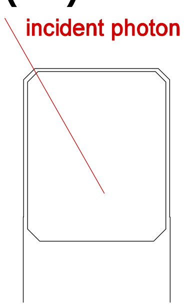




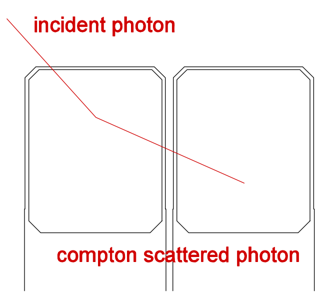
Bgnd Model

$$D_E = \int \beta_E \cdot R \cdot S + \alpha_E \cdot B_E$$

Single Event (SE)

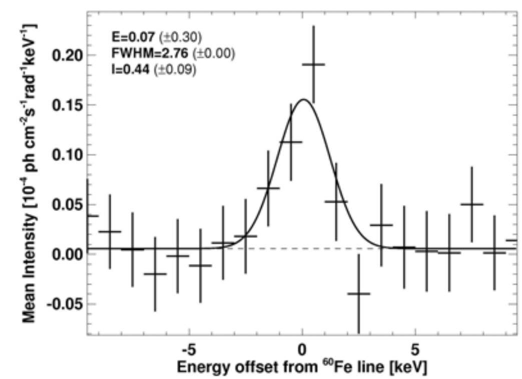


Multiple Event (ME)



Fit parameter

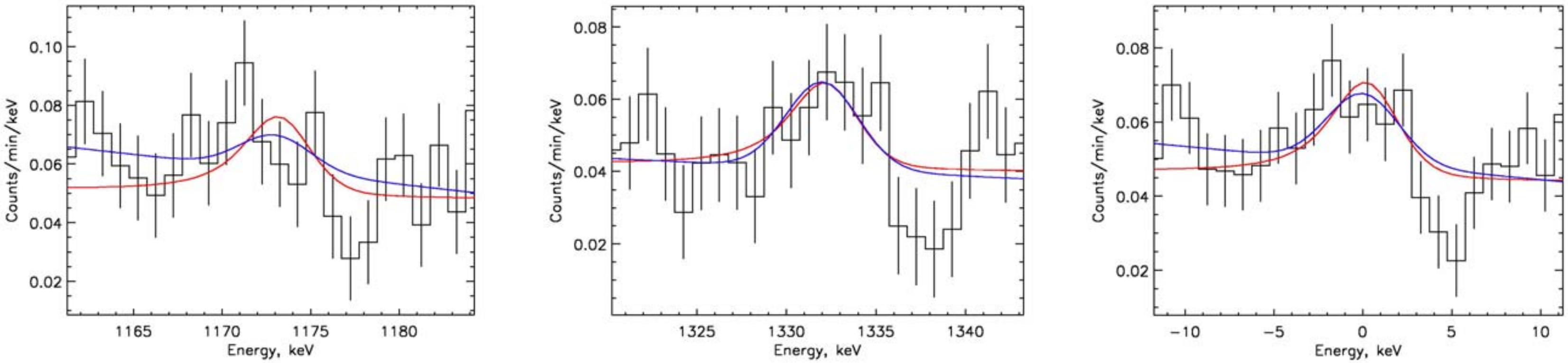
per energy bin



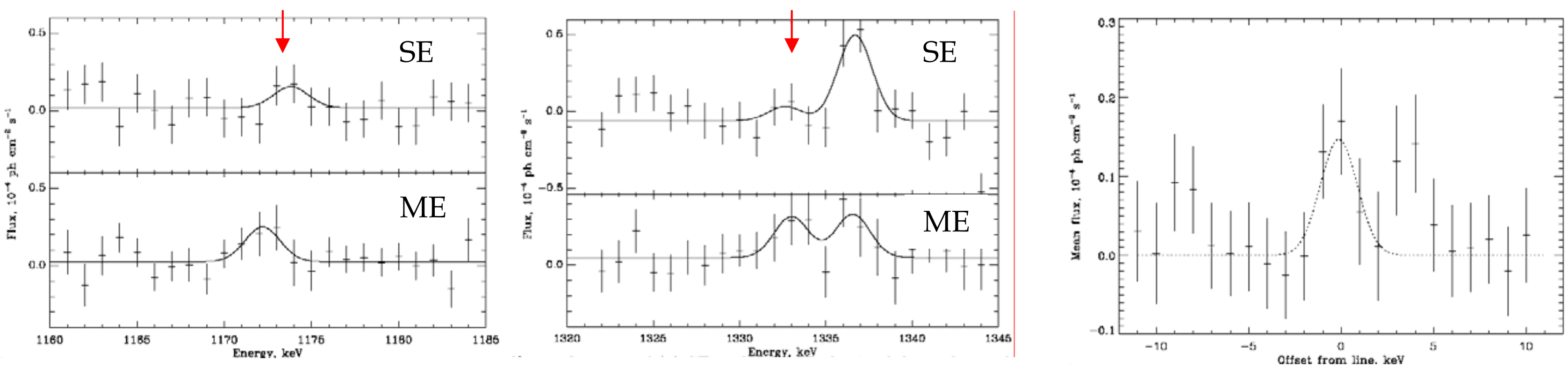
^{60}Fe Detection – Past (2005)

1173 keV | 1333 keV | Combined spectrum

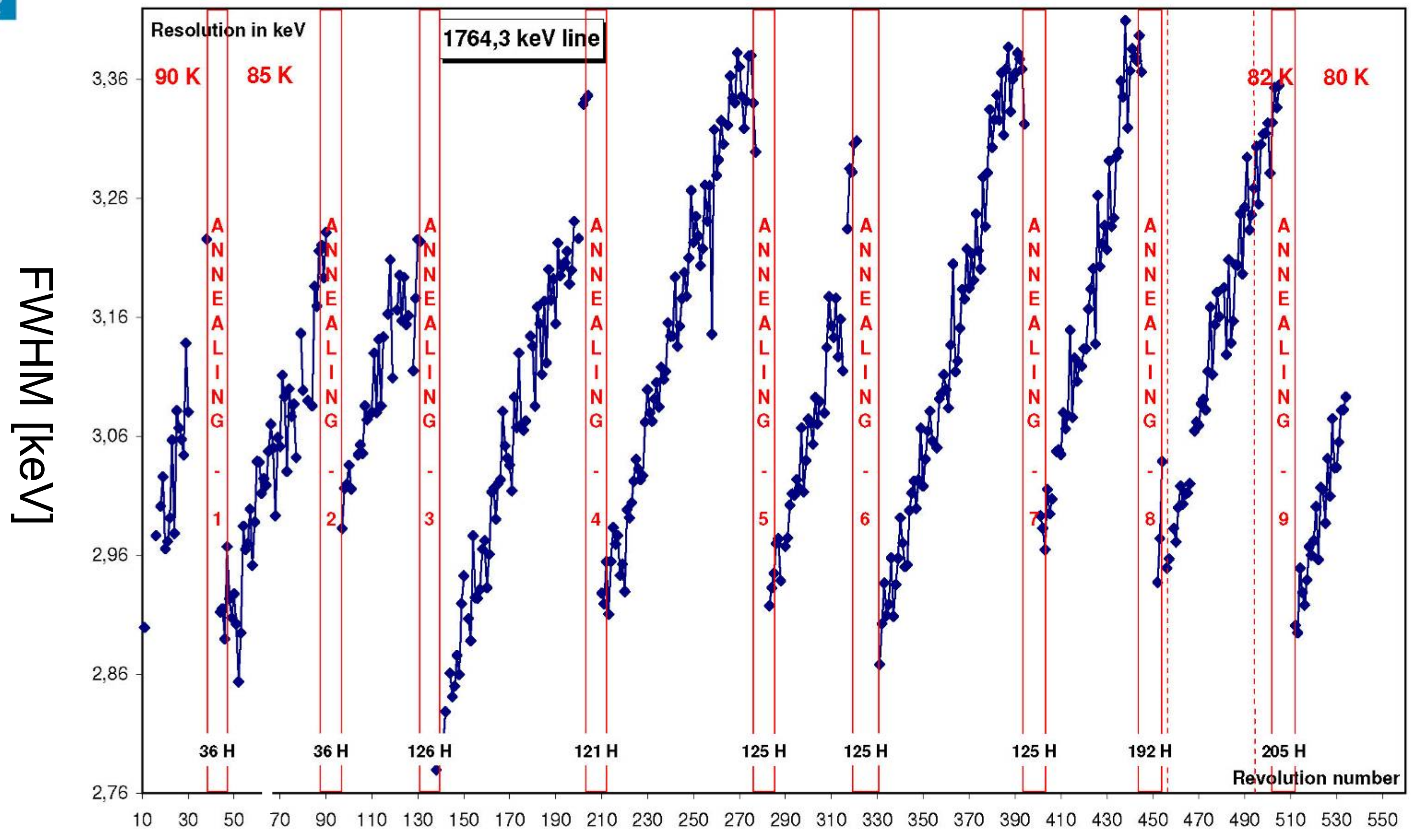
RHESSI (Smith)



SPI (Harris, 1 y data)



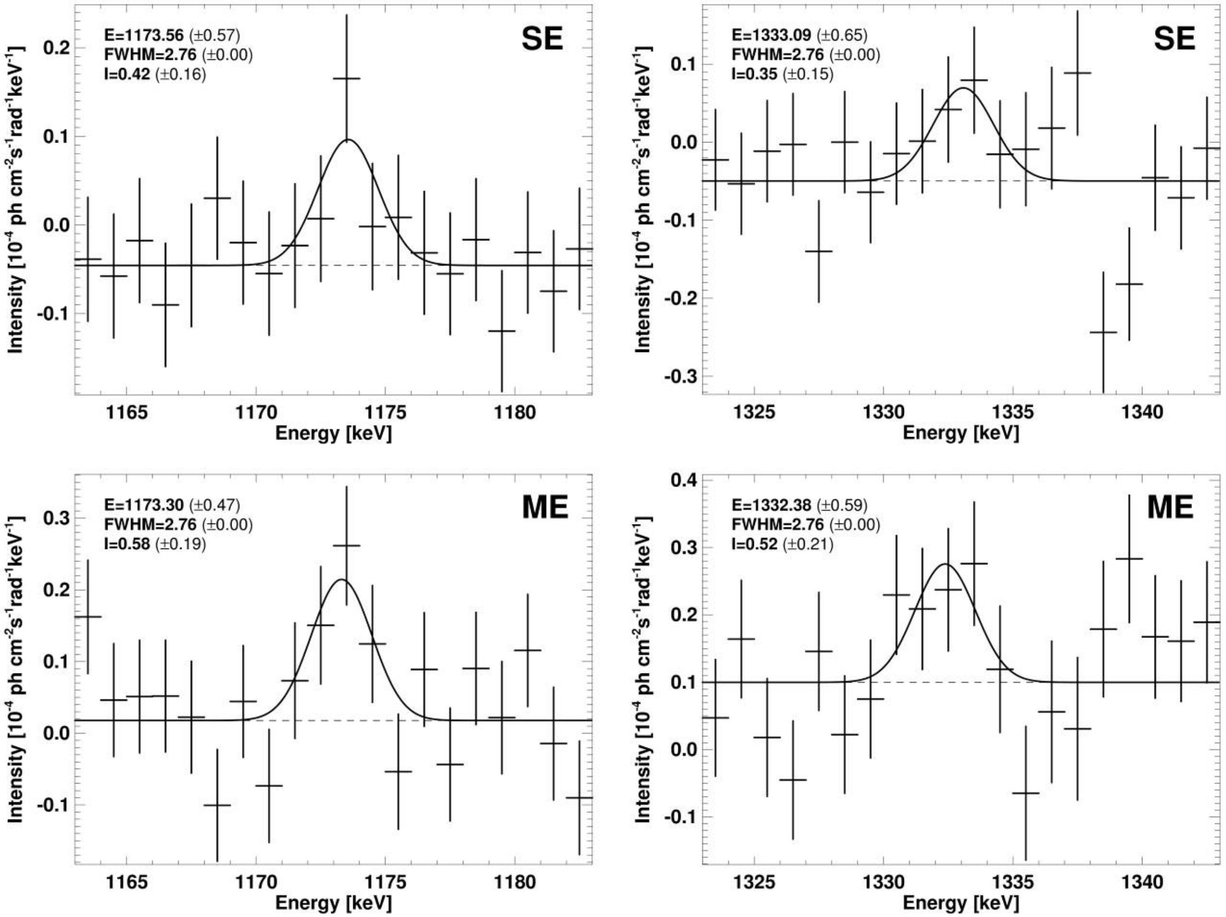
SPI Annealing: Recovering from Radiation Damage



Orbit Number (1 Orbit ≅ 3 d) *(J. P. Roques)*

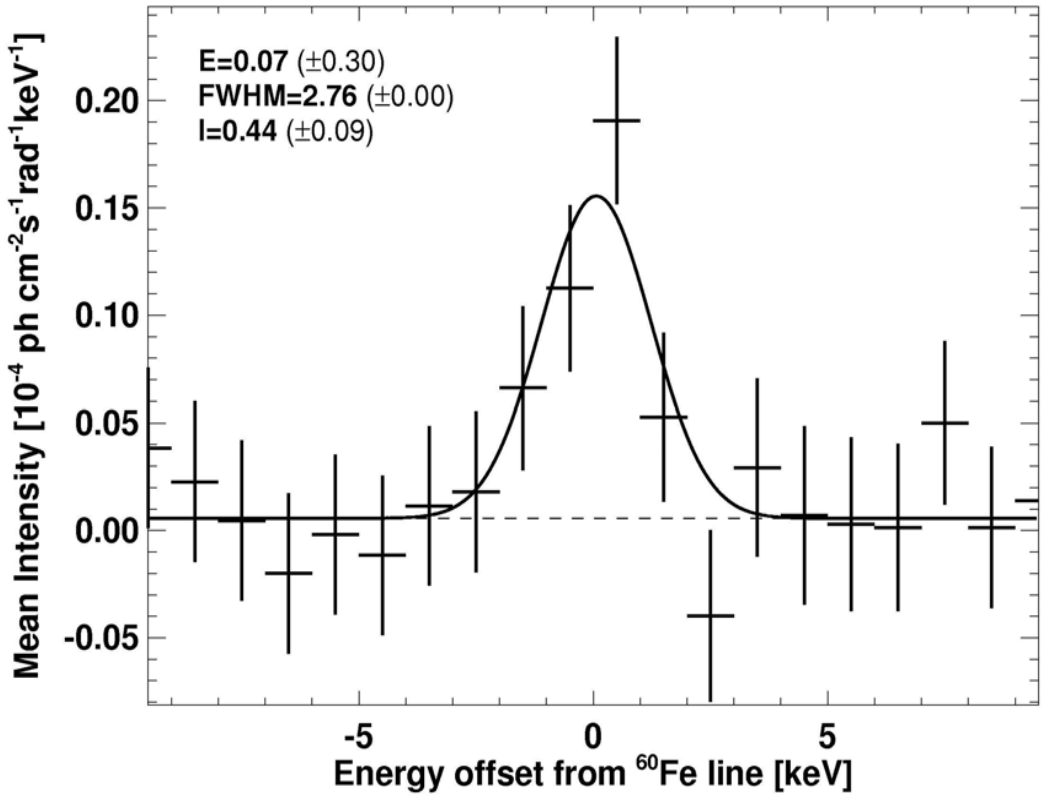
^{60}Fe Detection – Current (2007)

(Wang 2007)



^{60}Fe Detection – Combination

(Wang 2007)



→ Combined emission: $(4.4\pm0.9)\times10^{-5}$ ph cm^{-2} s^{-1} rad^{-1}

^{60}Fe / ^{26}Al Flux ratio

- Both produced by massive stars
- Relative measurement reduces systematics
- Radioactive decay

$$\dot{N} = \frac{N}{\tau} \quad \Rightarrow \quad \frac{I_\gamma\left({}^{60}\mathrm{Fe}\right)}{I_\gamma\left({}^{26}\mathrm{Al}\right)} = 2 \cdot \frac{\tau_{26\mathrm{Al}}}{\tau_{60\mathrm{Fe}}} \cdot \frac{N_{60\mathrm{Fe}}}{N_{26\mathrm{Al}}} = 2 \cdot \frac{\tau_{26\mathrm{Al}}}{\tau_{60\mathrm{Fe}}} \cdot \frac{26}{60} \cdot \frac{\langle M_{60} \rangle}{\langle M_{26} \rangle}$$

- Our analysis

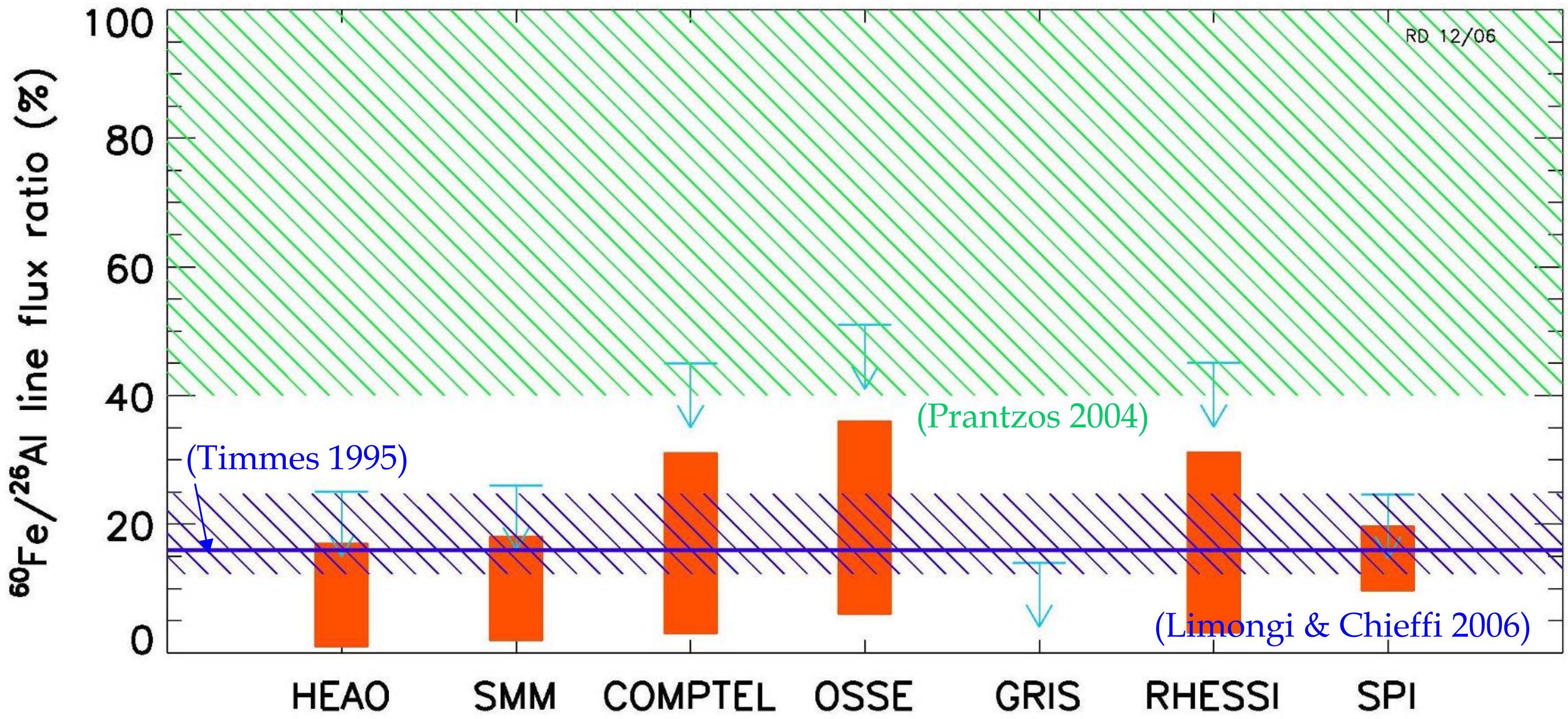
$$\frac{I_\gamma\left({}^{60}\mathrm{Fe}\right)}{I_\gamma\left({}^{26}\mathrm{Al}\right)} = 0.14 \pm 0.06 \quad \Rightarrow \quad \frac{\langle M_{60} \rangle}{\langle M_{26} \rangle} \approx 0.33$$

$1.1 \pm 0.3\ M_\odot$

$\approx 2.2 \times 10^{30}$ kg

Comparison to ^{26}Al

(from R. Diehl)



Summary and Prospects

- ^{60}Fe from the Galaxy has been clearly detected
- ^{60}Fe / ^{26}Al consistent with theoretical expectations
- Uncertainty of the SPI result is comparable to uncertainties in astrophysical models

- We now have > 4 y of data (Wang et al. 2.5 y) & additional 4+ years of INTEGRAL mission operations
- ^{60}Fe background models need to be improved
- Goal: Separate different Galactic regions (1st and 4th galactic quadrants, star forming regions)