Review of the observations of the positron annihilation emission in our Galaxy

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- History of the observations before INTEGRAL
- Observations with SPI/INTEGRAL
- Recent results

First 10s after the big bang :

Too few positrons (by 1 part in 10^9)

Today :

Too many positrons (> 0)

Real problem :

Too many explanations

for the origin of the positrons

Suggested possible origins of positrons

Galactic centre/bulge :

- Light dark matter	(Boehm et al. 2004)
- Q balls	(Kasuya & Takahashi et al. 2005)
- Starburst	(Dermer and Skibo, 1997)
- Color superconducting dark matter	(Oaknin & Zhitnitsky et al. 2005)
- Primordial black holes	(Frampton & Kephart et al. 2005)
- GRB/Hypernova	(Parizot et al. 2005, Cassé et al. 2005)
- Small-mass black holes	(Titarchuk & Chardonnet 2006)
- Millisecond pulsars	(Wang et al. 2006)
- SgrA*	(Cheng et al. 2006-2007, Totani 2006)
- Electroweak scale WIMPs	(Pospelov & Ritz, 2007)
-	

Galactic disk :

- ^{26}Al & ^{44}Ti decay	(Knödlseder et al. 2005)
- SNIa	(Prantzos 2006)
- Microquasars	(Guessoum et al. 2006)
- LMXBs	(Weidenspointner et al. 2007)
- Interactions in massive star winds	(Dermer et al)

Extragalactic :

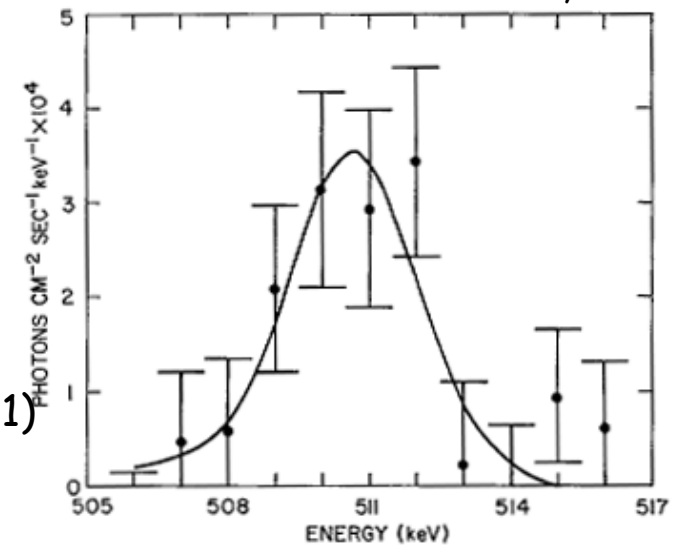
- GRBs	(Dermer et al, 2001, Furlanetto & Loeb 2002)
- Dead AGN in clusters	(Furlanetto & Loeb 2002)

HISTORY OF OBSERVATIONS

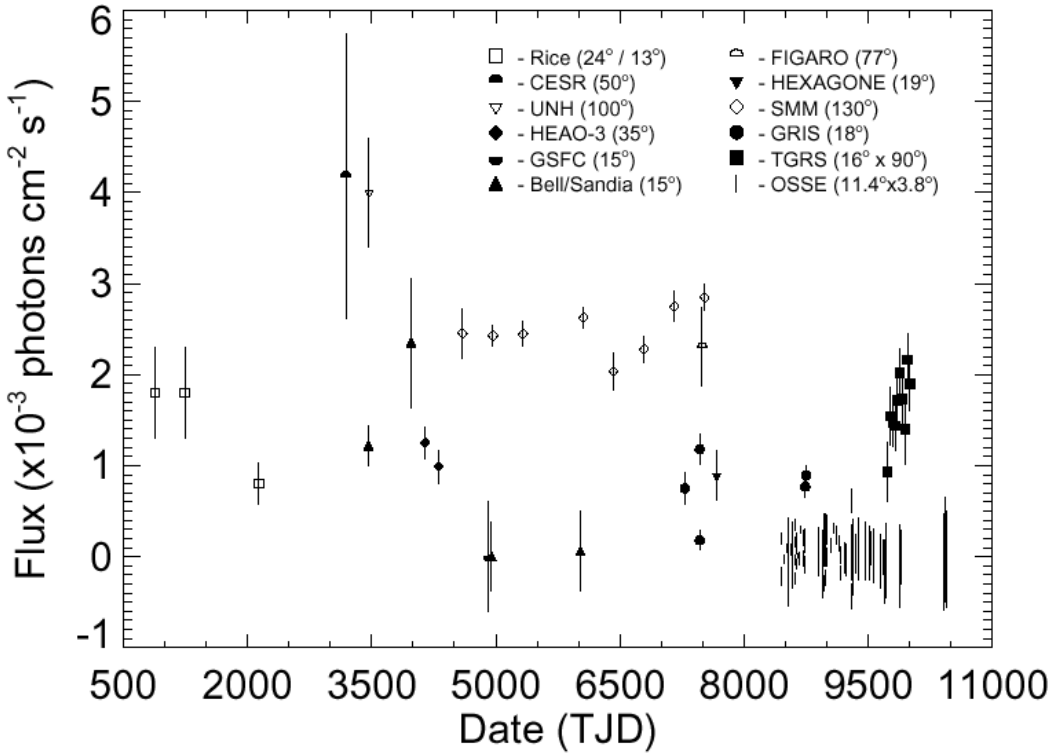
- 1970-1974 balloon borne NaI spectrometer (Rice)
- 1977-1989 balloon borne Ge spectrometers
- 1979-1980 HEAO3 -> variability (Riegler et al., 1981)
  -> Mahoney et al., 1994
- 1981-1985 SMM
- 1991-1997 OSSE -> First maps
- 1995-1997 TGRS
- 2002 (-2012?) Integral

$GC\ flux \sim 10^{-3}\ \gamma\ s^{-1}\ cm^{-2}$

Leventhal et al., 1978



Purcell et al., 1997



How can we learn what is going on ?

- Variability
- Identification of point sources
- Form of distribution of extended emission

  Life before slowing down and annihilating ~10^5 - 10^6 y
  Range ~ 100 pc
  Angular scale ~ degree

- Line shape

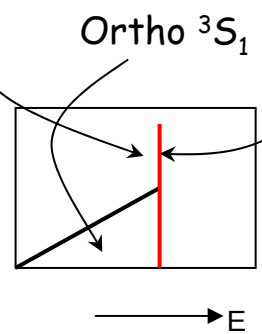
  Annihilation

  Direct annihilation before thermalisation -> (too) broad line
  Annihilation after thermalisation

  in hot plasma
  in warm gas
  in cold gas
  on grains

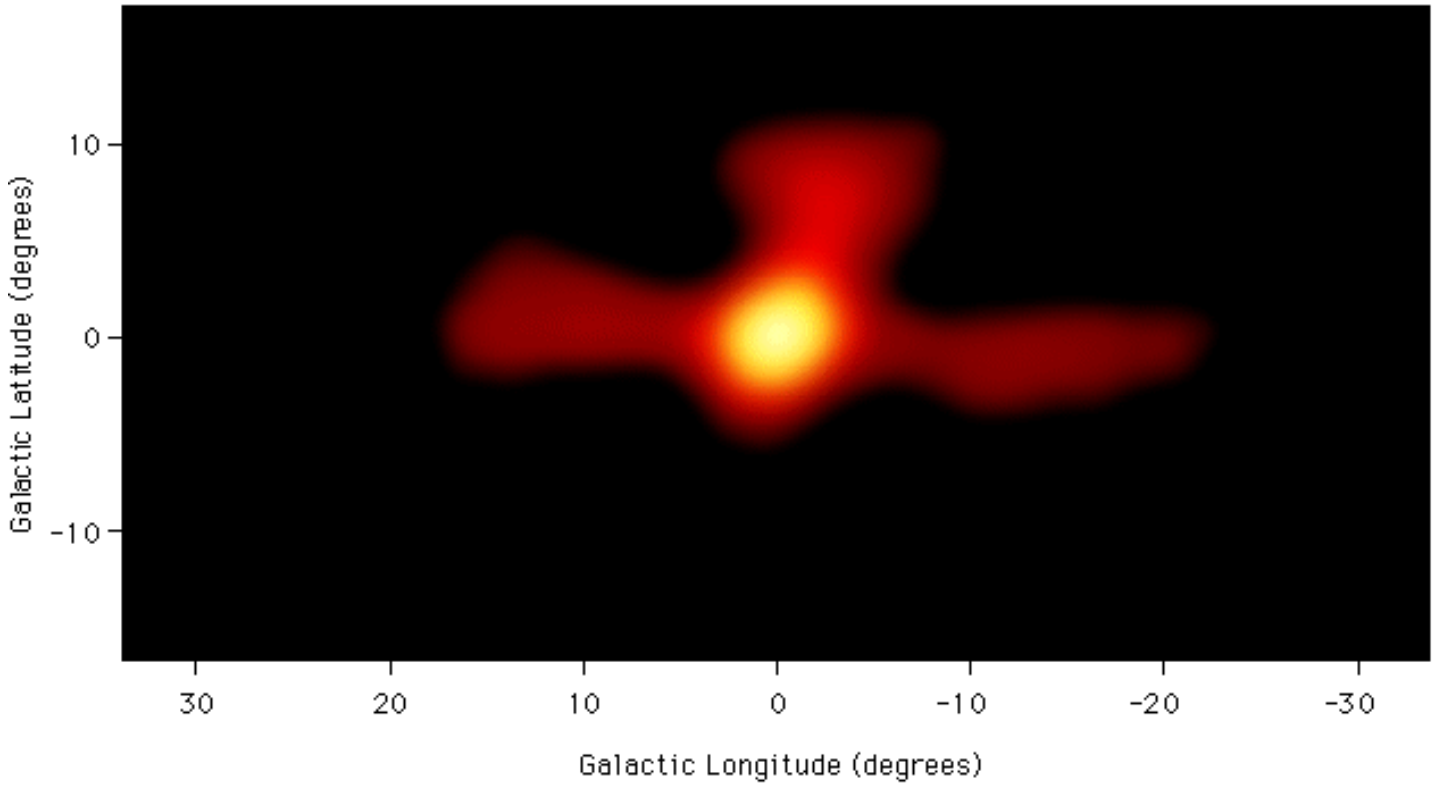
  } directly or via positronium

  Ortho $^3S_1$ 3:1 Para $^1S_0$



OSSE/SMM/TGRS

Imaging



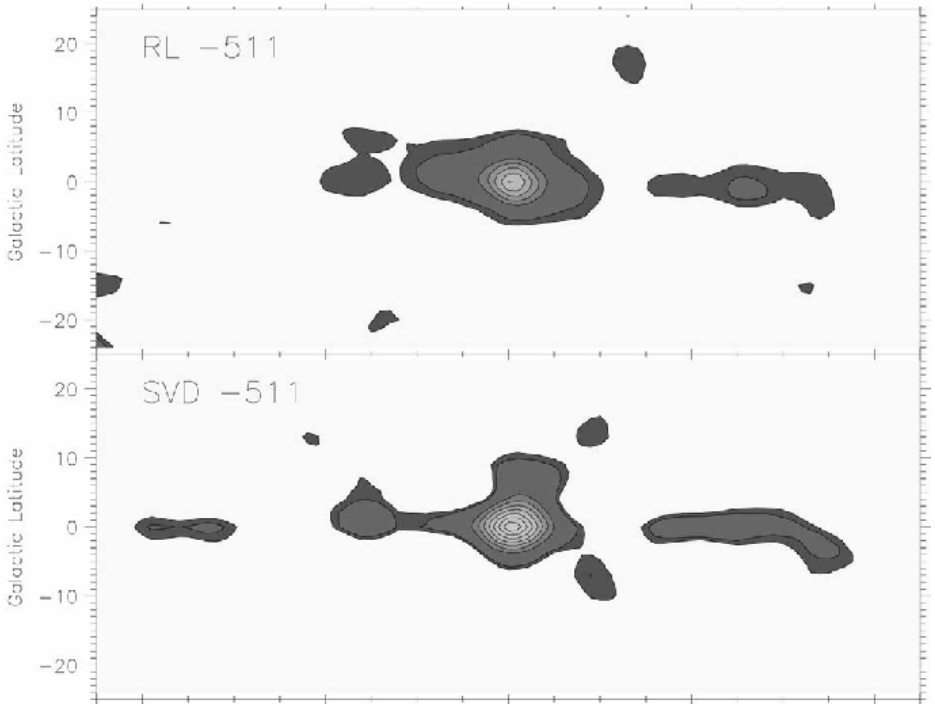
Purcell et al., 1997

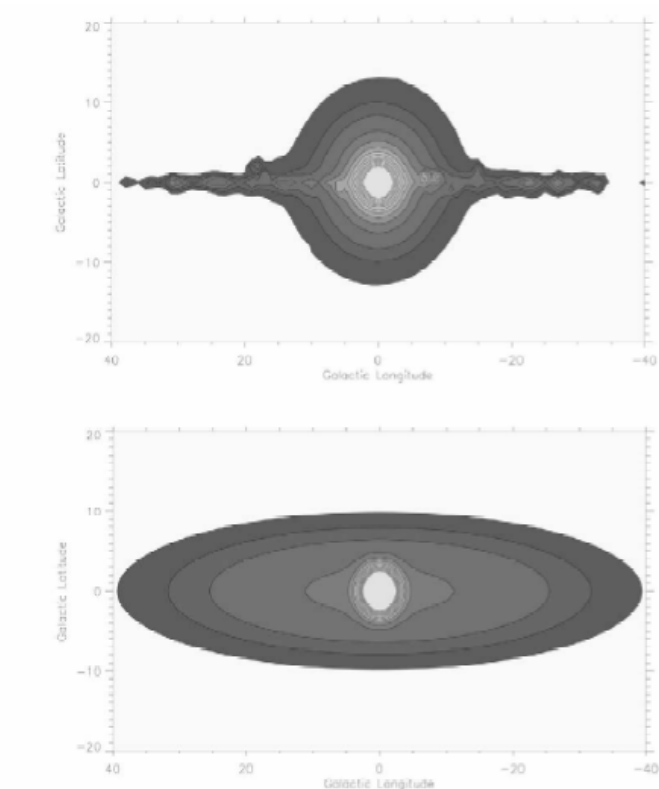
- Bulge : (3.3 ± 0.3) 10^{-4} γ s^{-1} cm^{-2}
- Disk : (11.5 ± 0.5) 10^{-4} γ s^{-1} cm^{-2}
- Positive Latitude Enhancement : (8.8 ± 0.5) 10^{-4} γ s^{-1} cm^{-2}

OSSE/SMM/TGRS

Extensive study of the morphology
Milne et al., 1999, 2000, 2002

- Bulge : (3.5 - 24) x 10^{-4} γ s^{-1} cm^{-2}
- Disk : (17.4 - 7.3) x 10^{-4} γ s^{-1} cm^{-2}
- PLE : (0.7 - 1.1) x 10^{-4} γ s^{-1} cm^{-2}





- GC flux ~ 10^{-3} γ s^{-1} cm^{-2}
- f_{Ps} = (93 ± 4)%
- Bulge to disk flux ratio: B/D ~ 0.2-3.3

OSSE/SMM/TGRS

Spectral analysis

Provide information on the physical conditions of the medium in which e^+ annihilate.

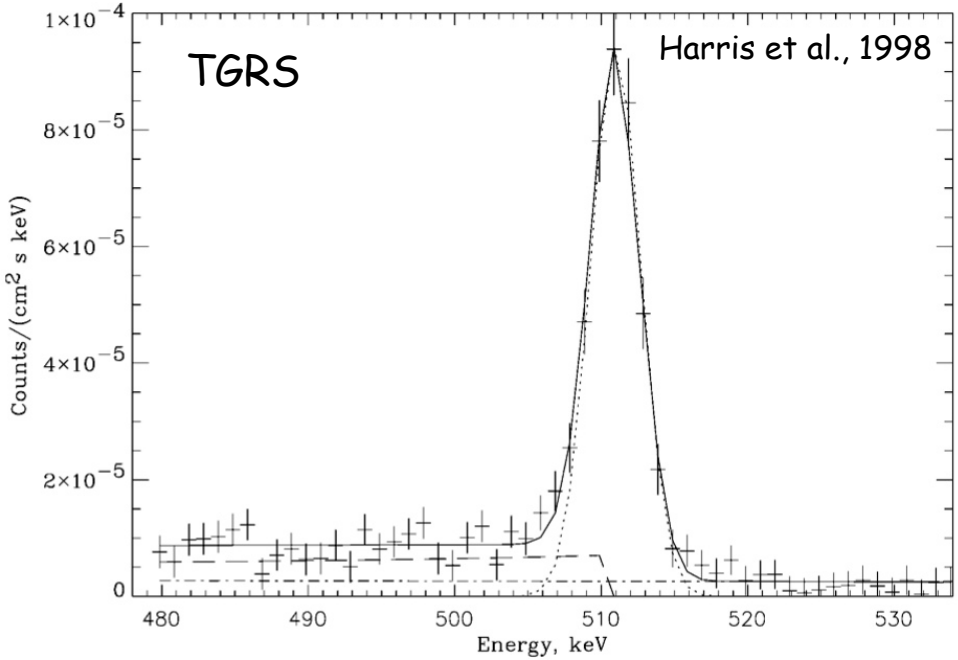
- TGRS data

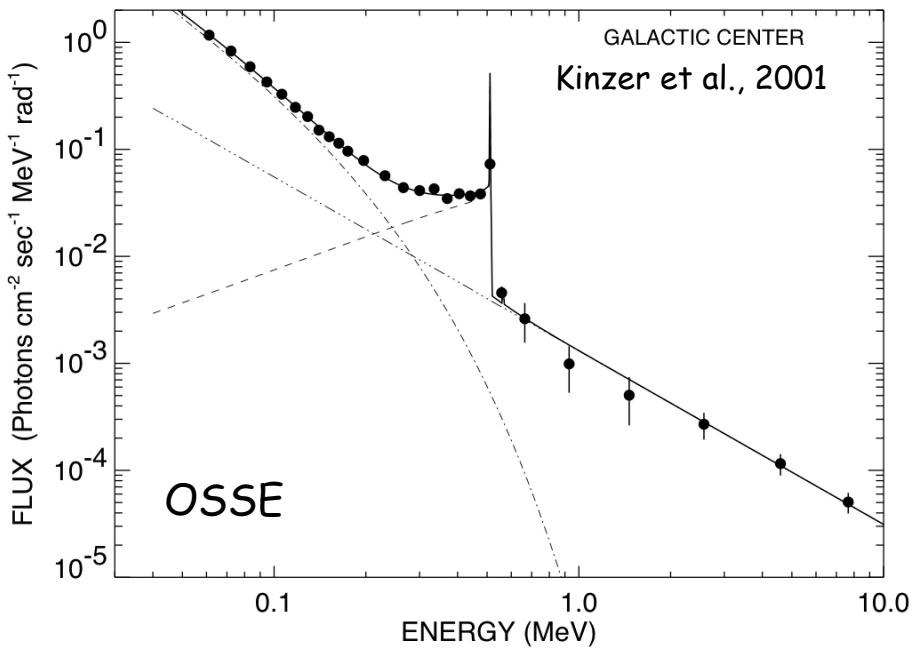
  Width : (1.8±0.5) keV
  Ps fraction : (94±4) %

- OSSE data

  Ps fraction : (93±4) %

-> No annihilation in molecular clouds
-> Annihilation in the hot phase is of minor importance





OBSERVATIONS WITH INTEGRAL / SPI

OBSERVATIONS WITH SPI

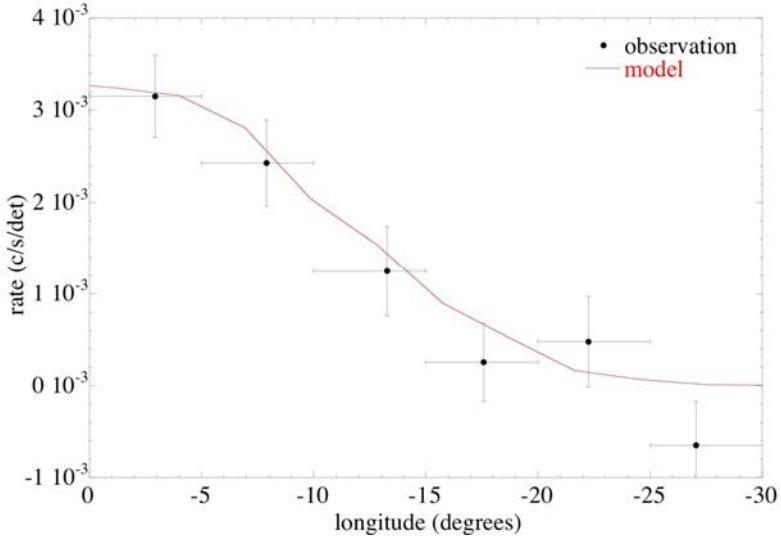
- **Early measurements of the 511 keV line (Jean et al. 2003)**

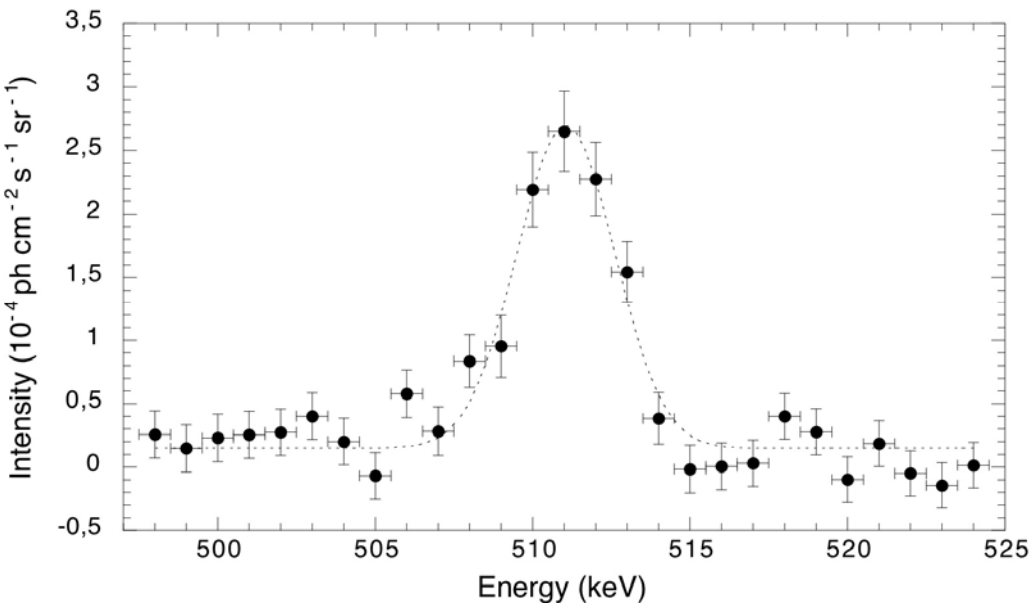
Observations from March to May 2003
(GCDE & GPS) exposure time ~ 1.7 Ms.

Evidence for an extended emission
FWHM ~ 10°

Spectral analysis :
Spectrum extracted by model fitting
- centroid : (511.0 ± 0.2) keV
- width : (3.0 ± 0.5) keV
- flux : (0.8 - 1.5) x 10^{-3} ph/s/cm^2.

Evidence for a Ps continuum





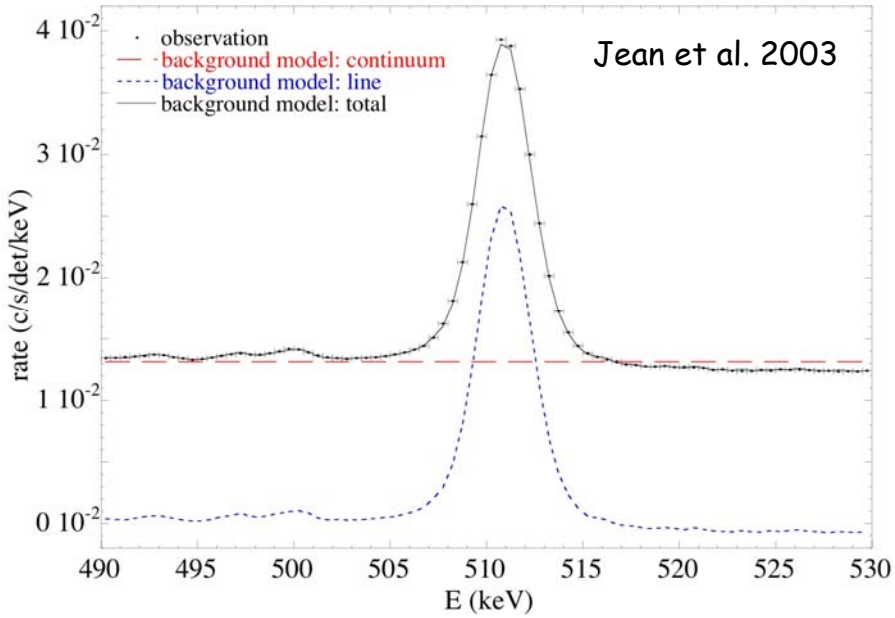
- **Remarks on the instrumental background**

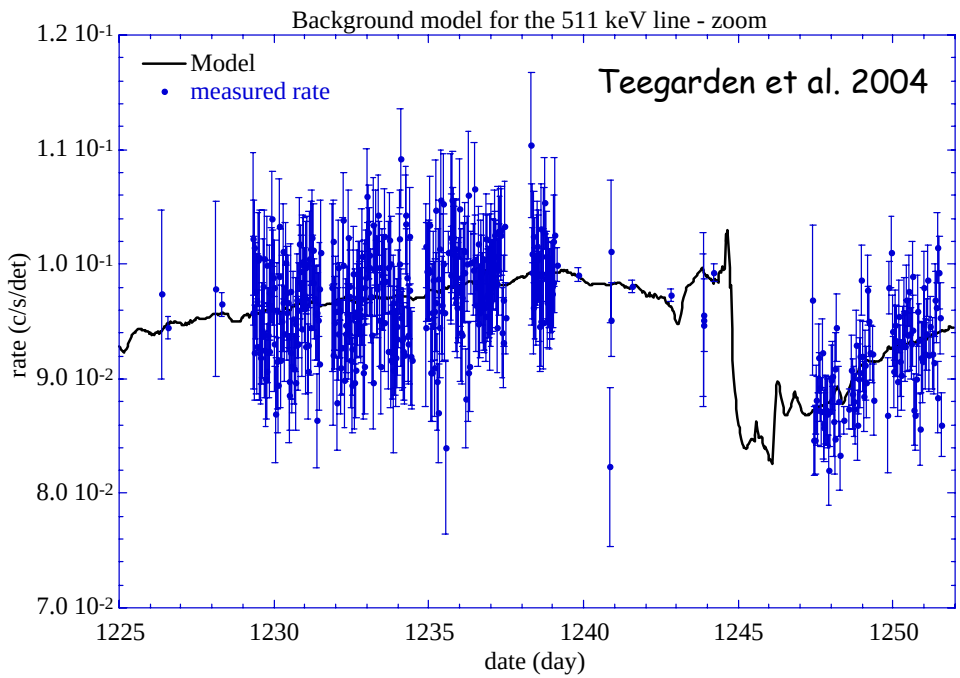
The S/N ratio is very weak (~1%)

Background modelling is required to extract the astrophysical signal.

Time variations of the background rate is estimated using the rate of saturating events in the GeDs.

$B(t) = \sum_i f_i(R_{GedSat}(t))$





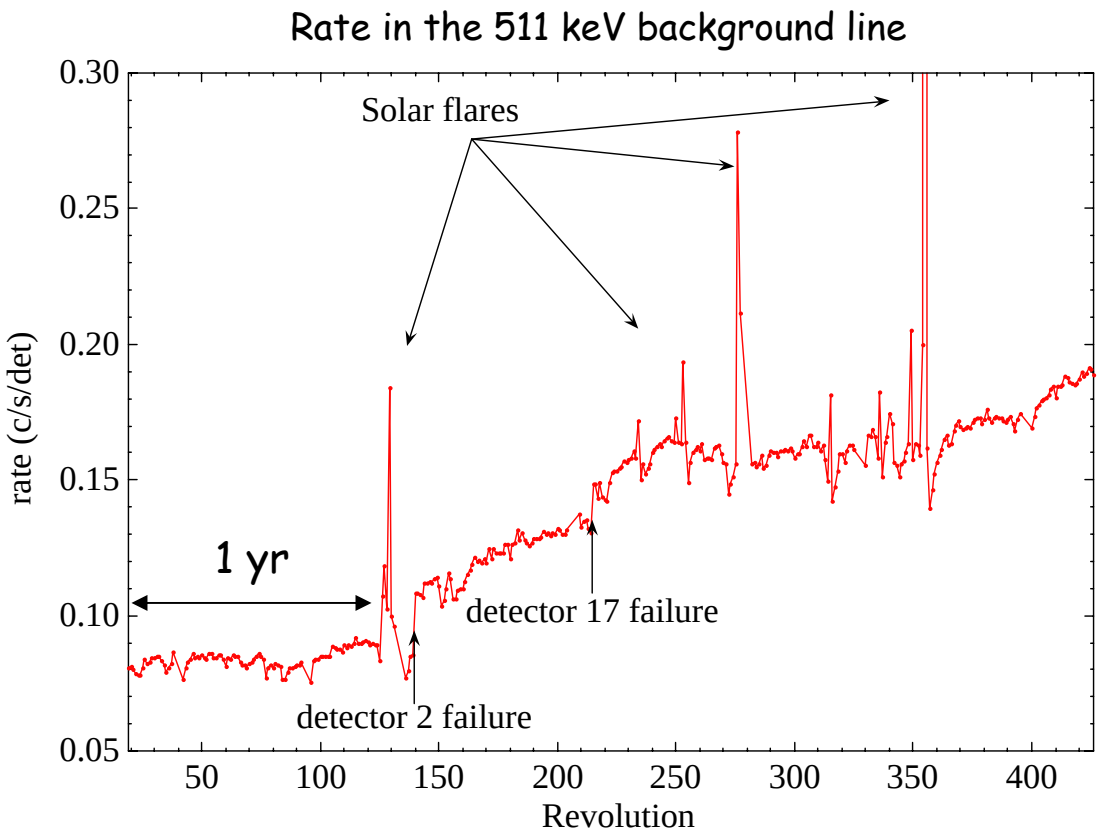
The importance of understanding the background

- Enhancement of the instrumental background
- Strong instrumental background variations due to solar flares and detector failures

=> To avoid systematic errors, the analysis is performed using a large number of parameters to fit the instrumental background

=> Further cleaning of the data

=> Loss in sensitivity, improved immunity from systematic errors



- **After ~10 month of observations**

- Search for point sources

A single point source is excluded

- Model fitting : 2D gaussian

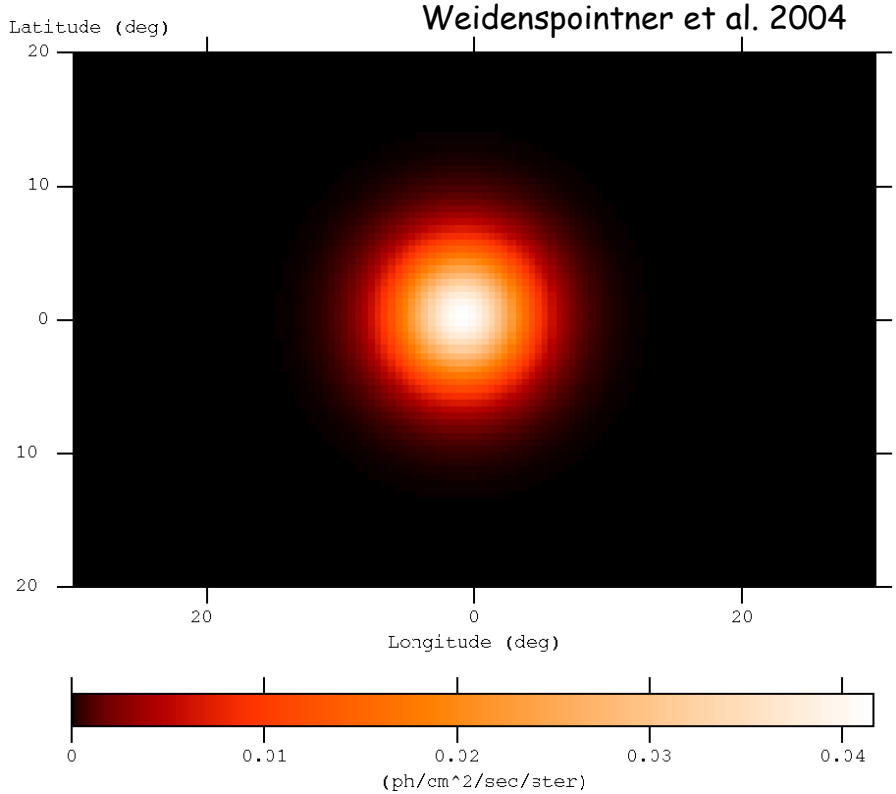
FWHM: 6^o - 12^o (95.5%)

position: $l = -1.0^o \pm 0.7^o$
$b = 0.3^o \pm 0.7^o$

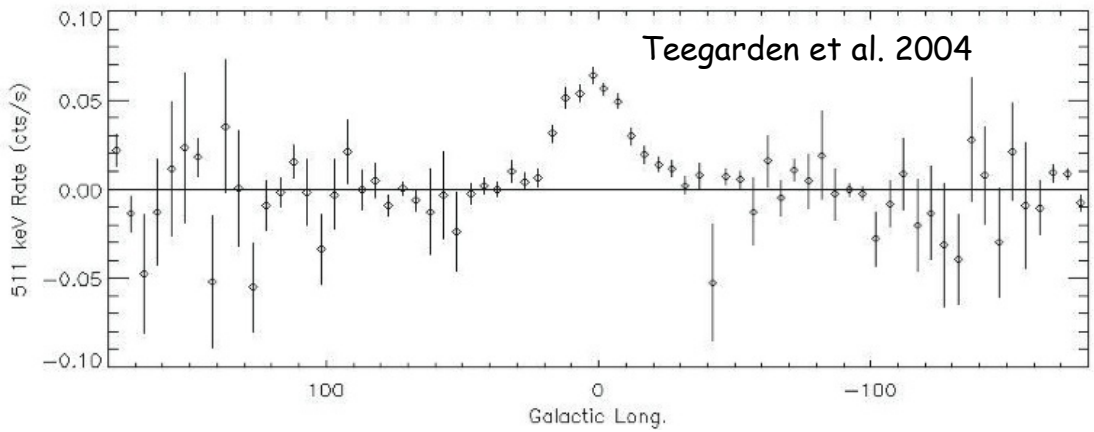
- The emission from the disk is not yet detected

=> B/D > 0.4-0.8

Weidenspointner et al. 2004

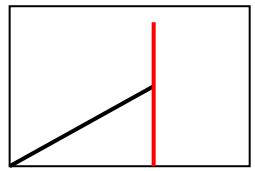


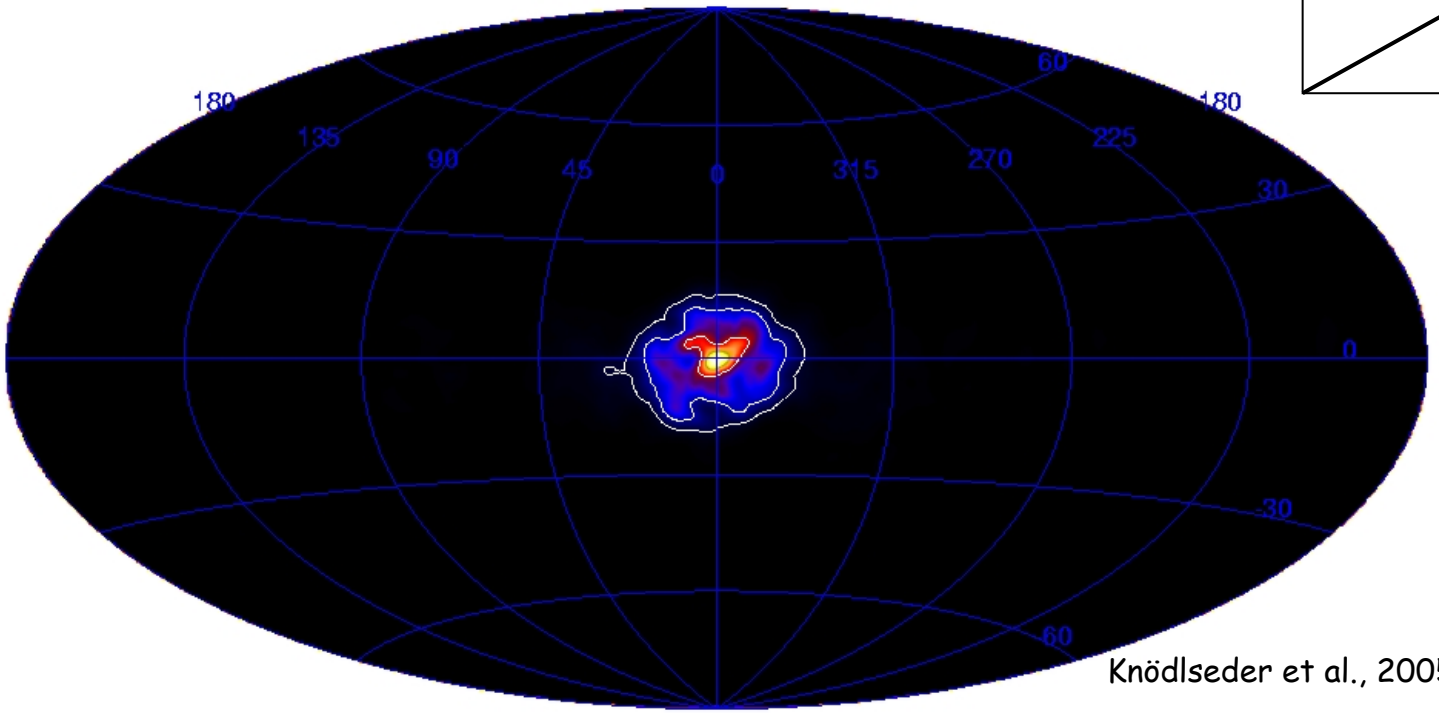
Teegarden et al. 2004



- **After one year of observations**

The all-sky distribution of the 511 keV line emission





Knödlseder et al., 2005

Morphological analysis by model fitting :

- Bulge : 2D Gaussian shaped emission : ~8°x7° FWHM
  Flux = (1.09 ± 0.04) x 10^{-3} γ/s/cm^{-2}

- Galactic disk : emission detected (~3-4σ)
  Flux ~ (4-6) x 10^{-4} γ/s/cm^{-2}

- No positive latitude enhancement

- **After one year of observations**

Morphological analysis

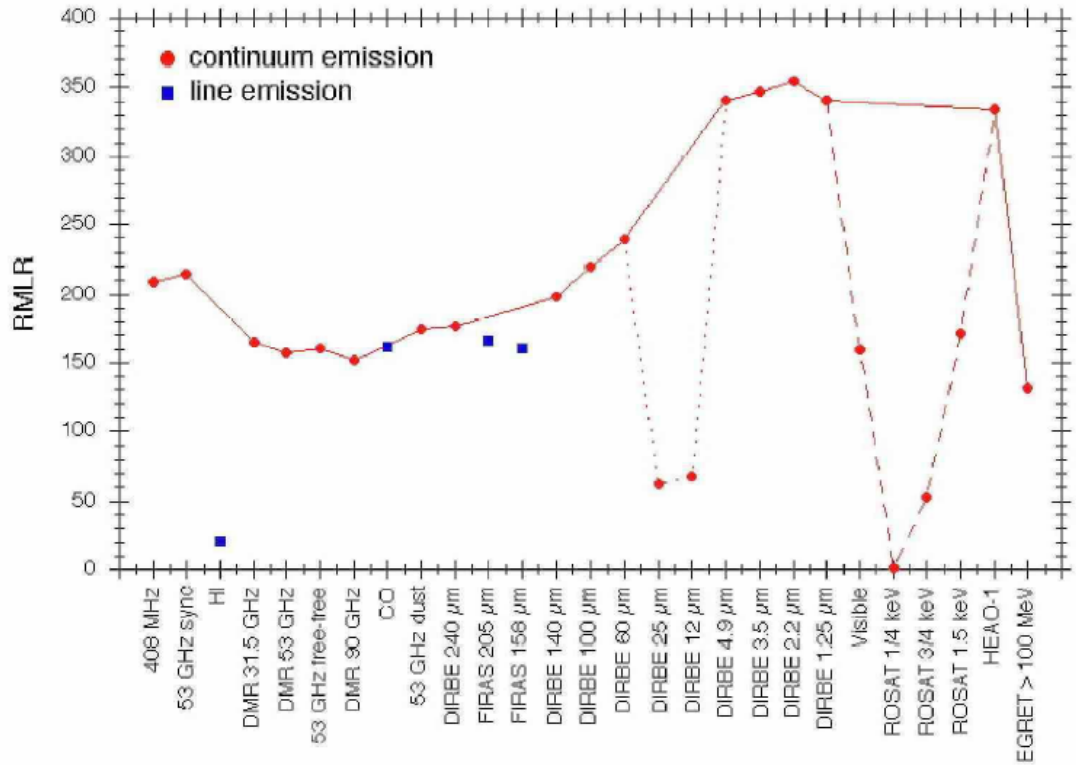
- Bulge to disk flux ratio

  B/D ~ 1-3

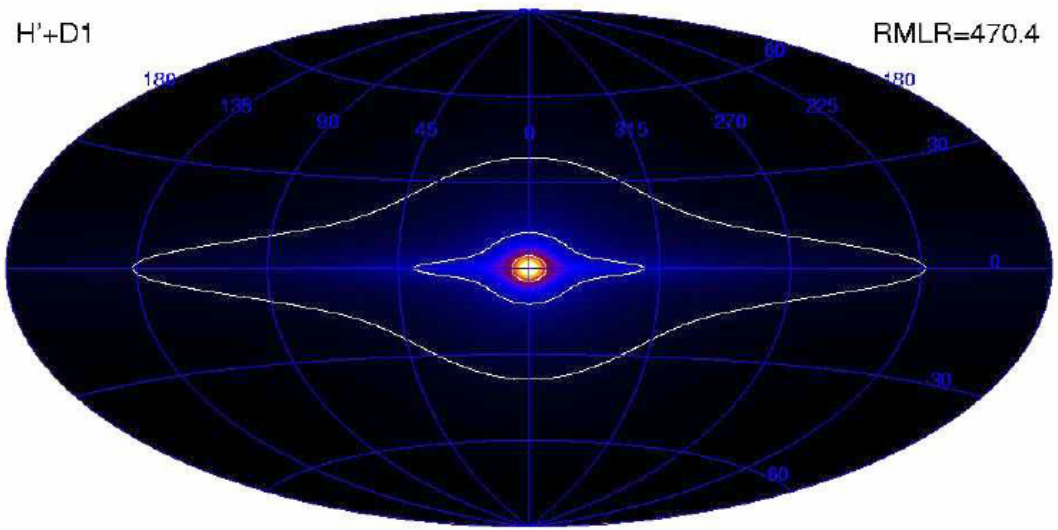
- Bulge to disk luminosity ratio

  B/D ~ 3-9

- Correlation with tracers
  & galactic distributions



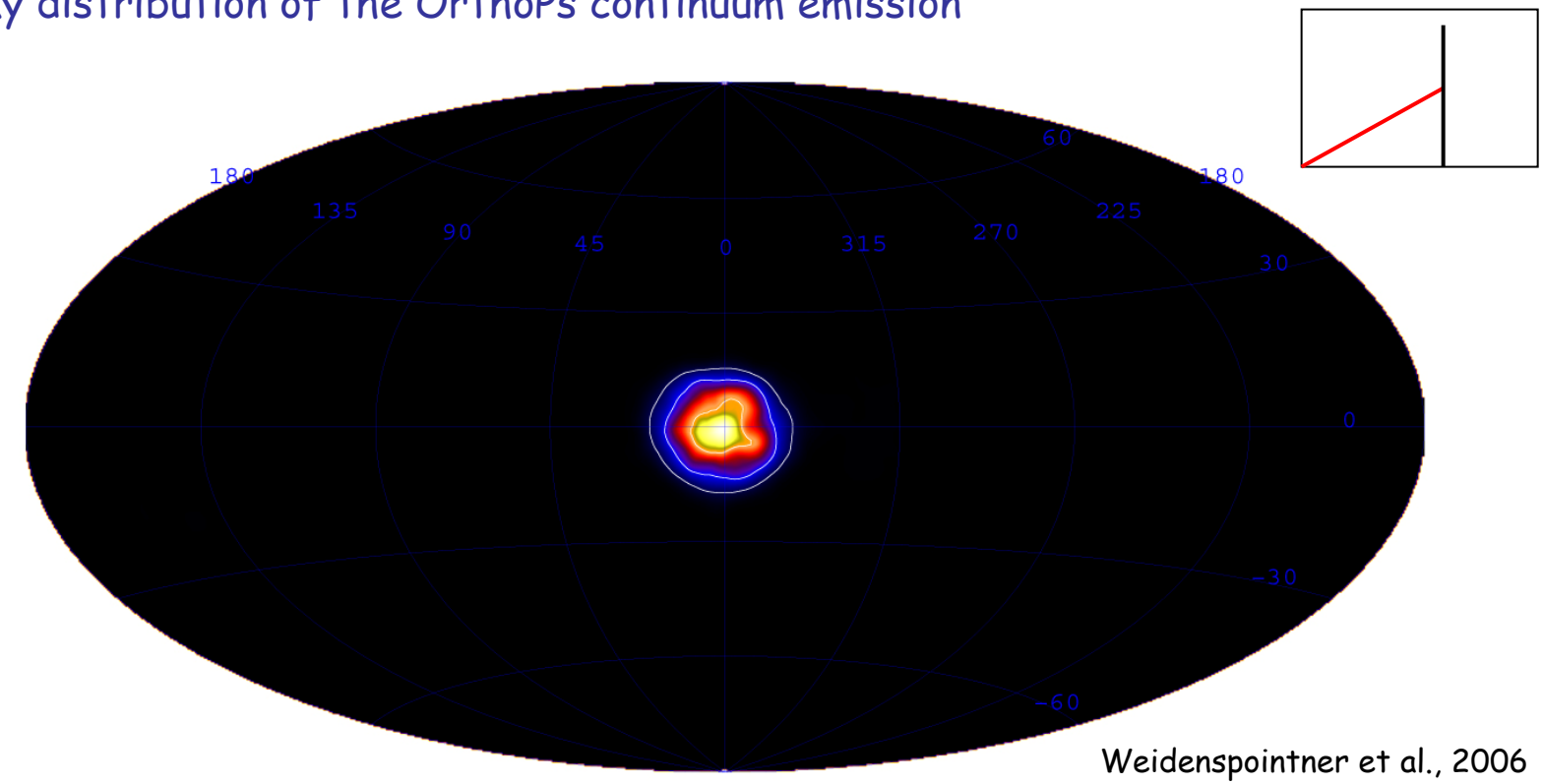
Knödlseder et al., 2005



Old stellar population favored

- **After one year of observations**

The all-sky distribution of the OrthoPs continuum emission



Weidenspointner et al., 2006

Intervals : 410-430, 447-465 and 490-500 keV

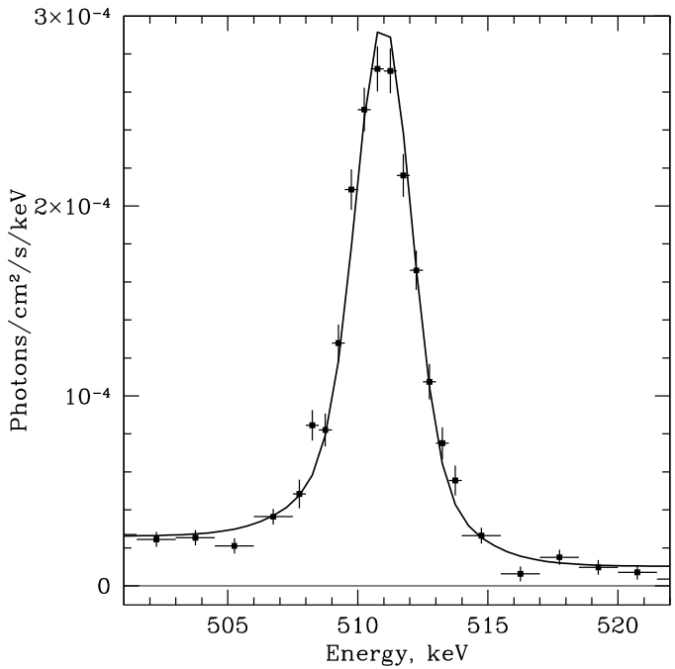
Morphological analysis by model fitting :

- emission detected at ~10σ.
- 2D Gaussian shape : ~8° FWHM compatible with the 511 keV distribution

- **After ~10 month of observations**

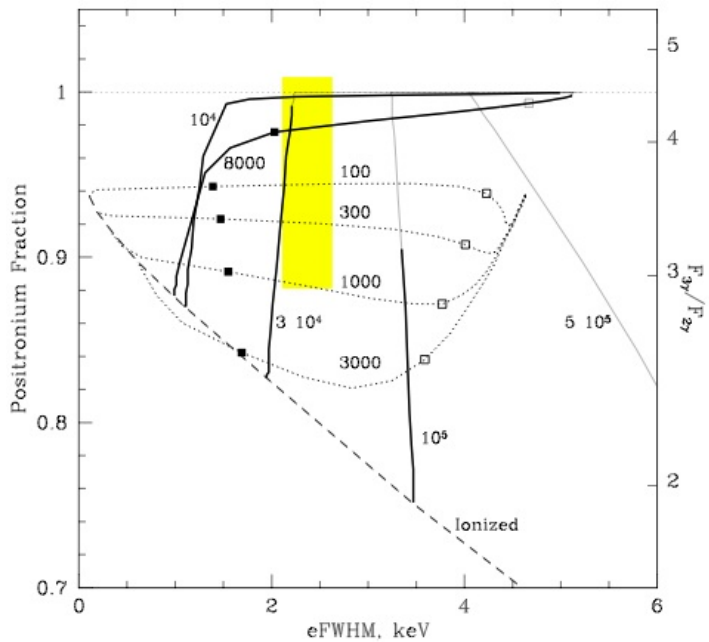
First detailled spectral analysis (Churazov et al. 2005)

- centroid : (510.954 ± 0.075) keV
- width : (2.37 ± 0.25) keV
- flux : (7.16 ± 0.35) x 10^{-4} ph/s/cm^2.
- Ps fraction : (94 ± 6) %



The shape of the line and the Ps fraction depend on the physical properties of the medium in which positrons annihilate.

Churazov et al. 2005 deduced a temperature in the range 7000-40000 K and an ionisation fraction >1%.

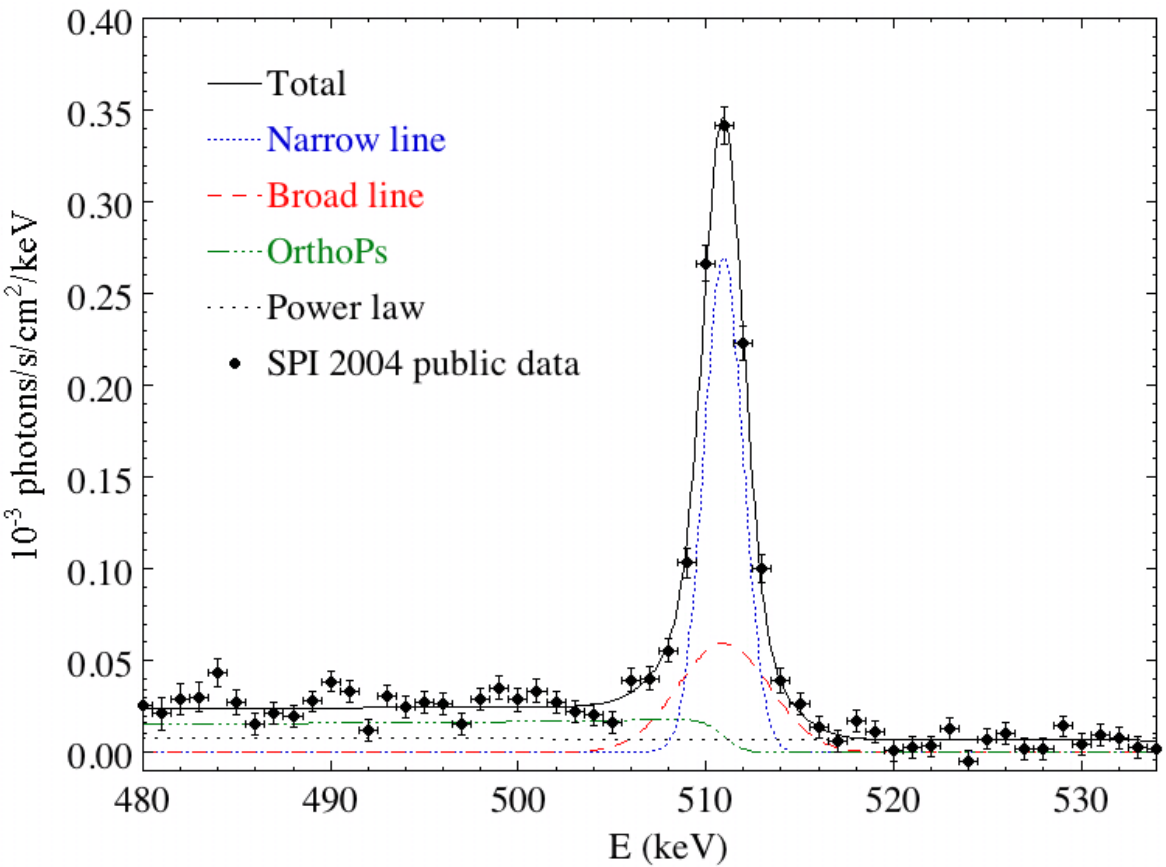


- **After one year of SPI observations**

Further spectral analysis (Jean et al. 2006)

- Line shape is complex.
- Detection of the broad 511 keV line emitted by annihilation of Ps formed in flight in the Galactic bulge.
- Positronium fraction in agreement with previous measurements.

Param.	Measured values
I_n	$(0.72 \pm 0.12 \pm 0.02)\ 10^{-3}\ s^{-1}\ cm^{-2}$
Γ_n	$1.32 \pm 0.35 \pm 0.02$ keV
I_b	$(0.35 \pm 0.11 \pm 0.02)\ 10^{-3}\ s^{-1}\ cm^{-2}$
Γ_b	$5.36 \pm 1.22 \pm 0.06$ keV
$I_{3\gamma}$	$(4.23 \pm 0.32 \pm 0.03)\ 10^{-3}\ s^{-1}\ cm^{-2}$
A_c	$(7.17 \pm 0.80 \pm 0.06)\ 10^{-6}\ s^{-1}\ cm^{-2}\ keV^{-1}$
f_{Ps}	(97±2) %



Expected 511 line width for different annihilation environments (keV FWHM)

	---------- Fraction of grains ---------		
Phase	$x_{gr} = 1$	$x_{gr} = 0$	$x_{gr} = 10$
Molecular	2.39	2.39	2.39
Cold	3.00	3.00	2.92
Warm neutral	4.78	4.76	4.74
Warm ionized	1.02	1.00	1.19
Hot	1.99	11.0	1.96
Combined	2.26 (1.18)	2.17 (1.15)	2.17 (1.37)

Table 2. Fraction (in %) of positrons forming positronium in flight, in a completely neutral medium.

References	H	H_2	He
BRD79	95	93	–
Brown & Leventhal	–	89.7 ± 0.3	80.7 ± 0.5
Wallyn et al. (1994)	98	90	–
Chapuis et al. (1994)	–	–	78
Guessoum et al. (2005)	95.5	89.6	81.7

Measured positronium fraction:

OSSE - Milne et al (2000)	(93±4) %
TGRS - Harris et al ()	(94±6) %
SPI Churazov (2005)	(94±6) %
SPI - Jean et al (2006)	(97±2) %

CONCLUSIONS

- What's new

- No positive latitude enhancement
- More accurate measure of the B/D ~ 0.7-2 (Weidenspointner et al. 2006)
- Better constraint on the morphology of the emission in the bulge
- Bulge not offset from centre
- Detection of the annihilation of positronium formed in flight (Γ ~ 5.8 keV)
- First measurement of T and ionisation fraction of annihilating medium
- Spectro-imaging : extraction of the spectra from different galactic regions
- Asymmetric emission from the disk correlated with LMXBs distribution

Other interesting investigations :
- Update of annihilation rates (Guessoum et al. 2005)
- Constraints on the initial energy of e^+ (Beacom & Yüksel 2006, Sizun et al. 2006-2007)
- Propagation & diffusion of e^+ in the ISM (Jean et al., 2006, Gillard et al. 2006, 2007)

-What's coming next

- Better spectral analysis (shift, line shape, f_{Ps}) of the emission from the disk
- Annihilation emission from ^{26}Al decays in Cygnus region
- Detailed morphology of the emission from the bulge
- ...

End