

# hard X-ray and soft $\gamma$ -ray Galactic diffuse emission



**What do we know after 6 years of Integral?**

& a very short status on the future of the mission

R. Terrier APC

# Diffuse emission 6 years ago

$\sim 10 \text{ MeV} < E,$

- truly diffuse processes

$\sim 300 \text{ keV} < E < 511 \text{ keV}$

- Positronium decay (in the Galactic bulge)

a few keV  $< E < \sim 300 \text{ keV}$

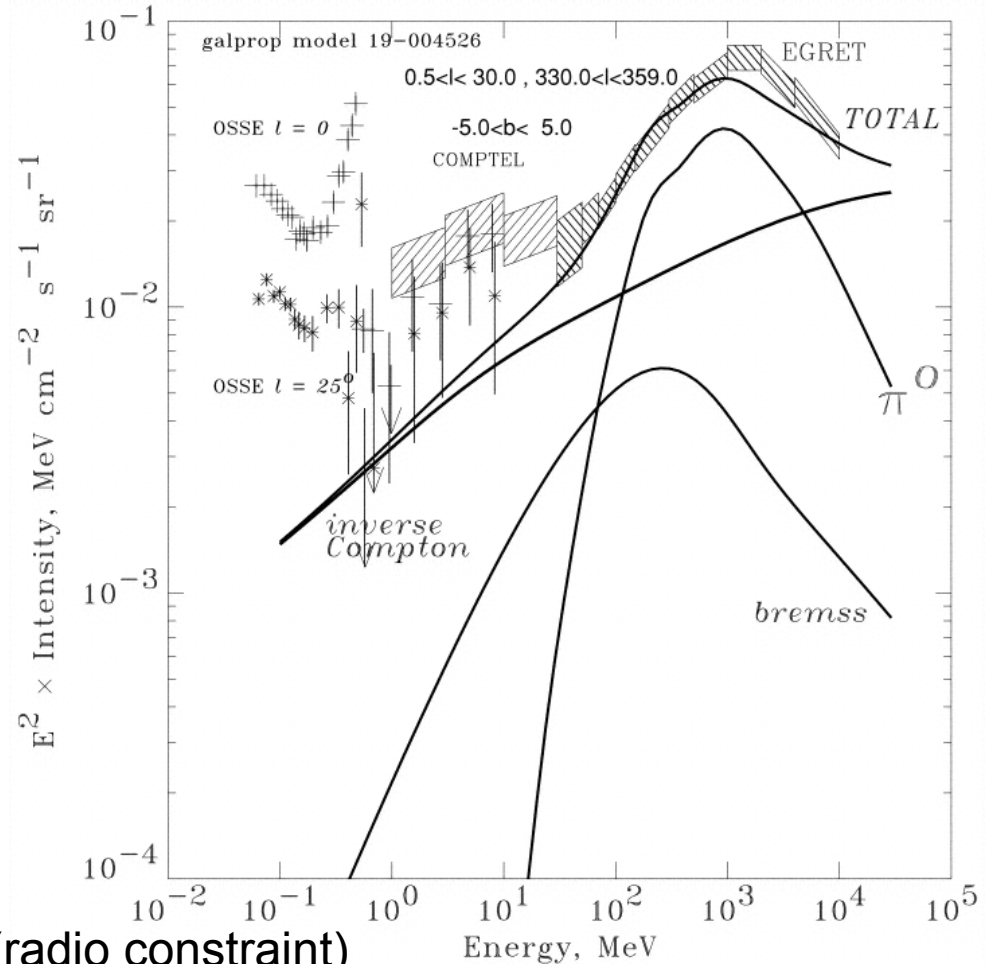
- Level of point sources contribution uncertain

Possible diffuse processes:

IC on low E  $e^-$  population : too low (radio constraint)

Bremsstrahlung of low E  $e^-$  population: too much ionization & high power

An important contamination from point sources is assumed



## Diffuse emission 6 years ago

OSSE (>50 keV) : collimator with no imaging capability

measure total Galactic emission (sources + diffuse) (*Kinzer et al. 1999*)

necessity to make simultaneous observations with “imaging” telescopes:

– SIGMA (coded mask instrument): (*Purcell et al. 1996*)

Sensitivity of ~ 30 mcrab, 40 to 60% of total emission is diffuse

– RXTE: (*Valinia, Kinzer & Marshall 1999*)

in Scutum arm ( $l=30^\circ$ )

~50% and 70% of diffuse at 60 and 100 keV

RXTE: (*Valinia & Marshall 1998, RevnisteV 2003*)

Low energy (<20 keV) measurement of Galactic ridge emission

If the residual emission is due to discrete sources, 10 sources of flux  $5 \cdot 10^{-3}$  ph./cm<sup>2</sup>/sec/MeV at 100 keV must be present in the field of view of OSSE to make up the spectrum. Because no such class of sources with a uniform space density in longitude is known, the emission at about 100 keV is probably of diffuse origin

*Pohl (1998)*

October 17th 2002

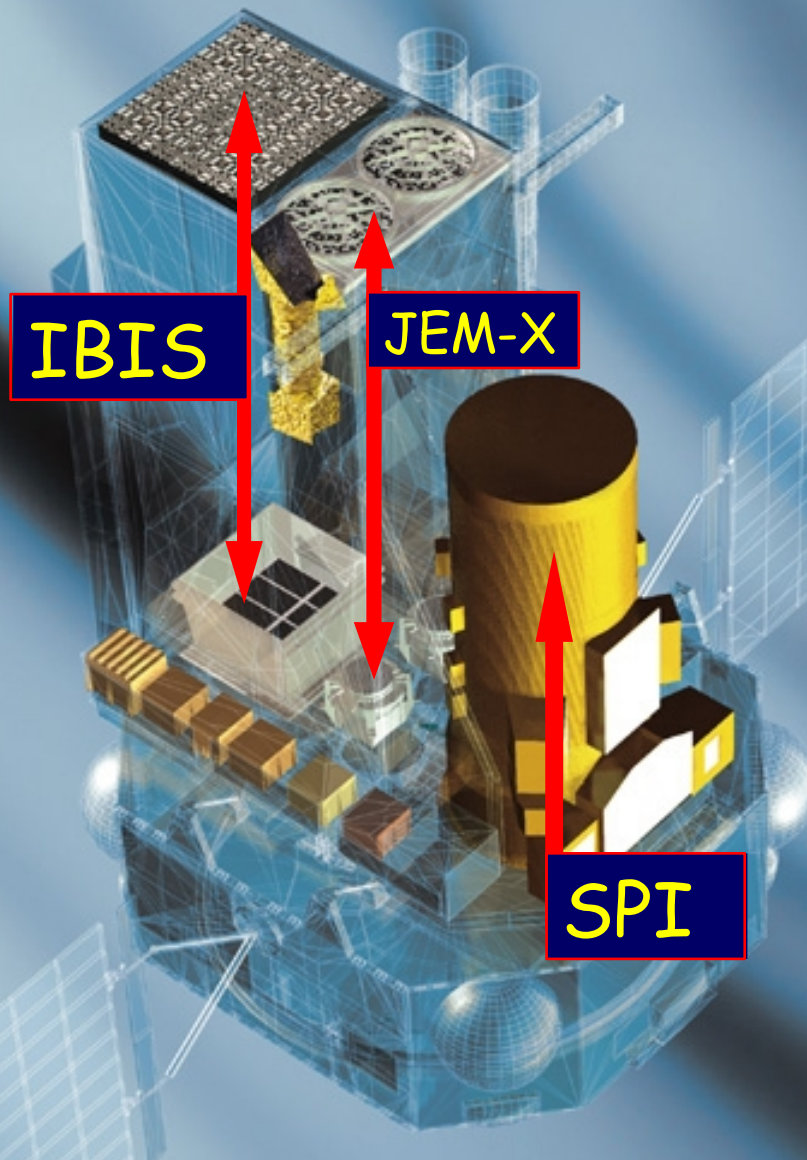




# INTEGRAL

**Imager: IBIS/ISGRI**

15keV-2 MeV  
16000 pixels CdTe  
FoV: 9° (tot. coded)  
PSF : 12' (FWHM)  
sensitivity ~ 1mCrab



**Spectrometer SPI**

20 keV – 10 MeV  
19 détecteurs Ge  
E resolution 2.5 keV @  
1 MeV  
PSF 2.6° (FWHM)  
FoV: 16° (tot. coded)

# The IBIS/ISGRI sky (20-60 keV)

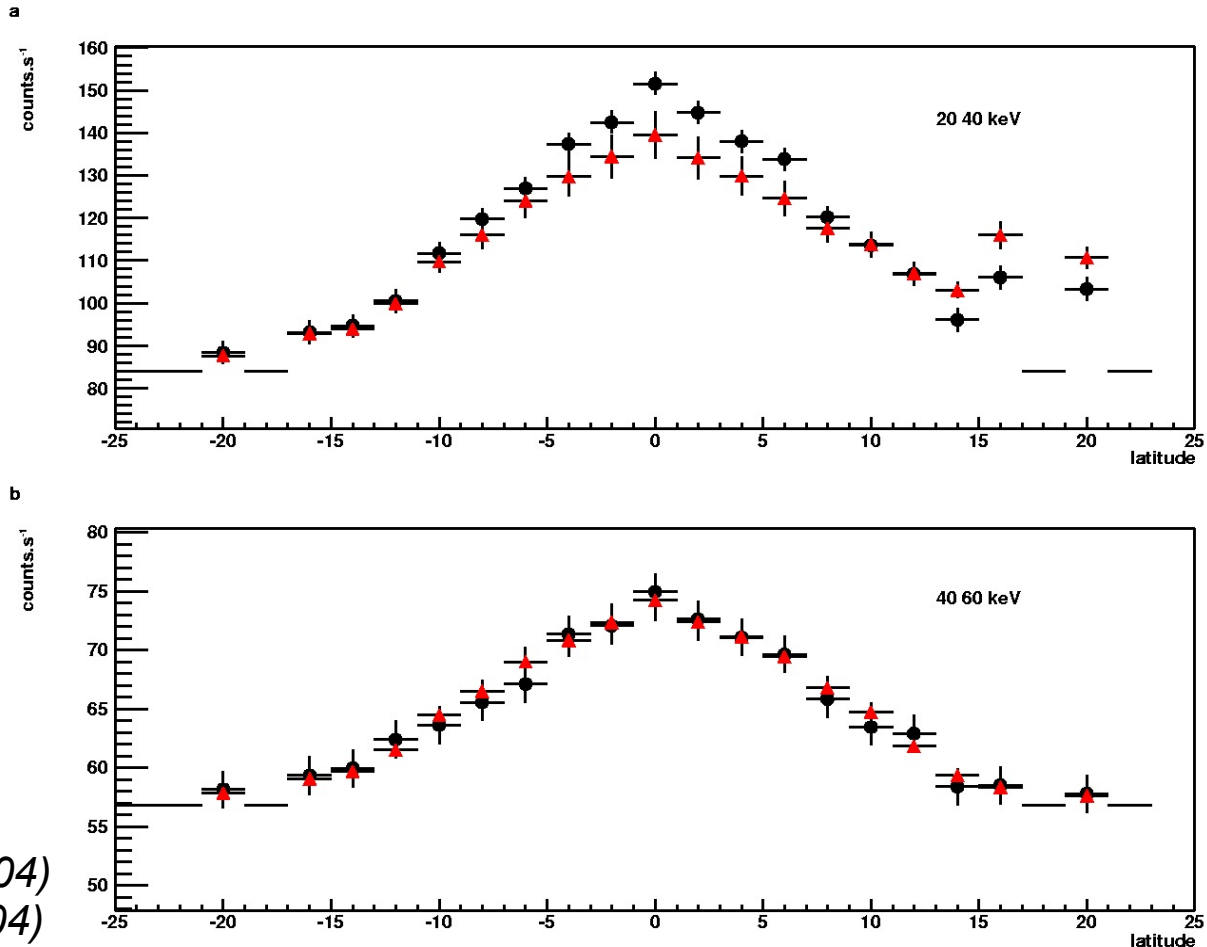


~400 sources  
mostly LMXB & HMXB  
AGNs  
Cvs  
Pulsars/AXP/PWNe  
SNRs  
tens of unidentified  
*Bird et al (2007), Krivonos et al (2008)*

# Diffuse emission ( $E < 100$ keV) with Integral?

IBIS/Isgri is able to resolve a large number of sources emitting in the hard X-ray range

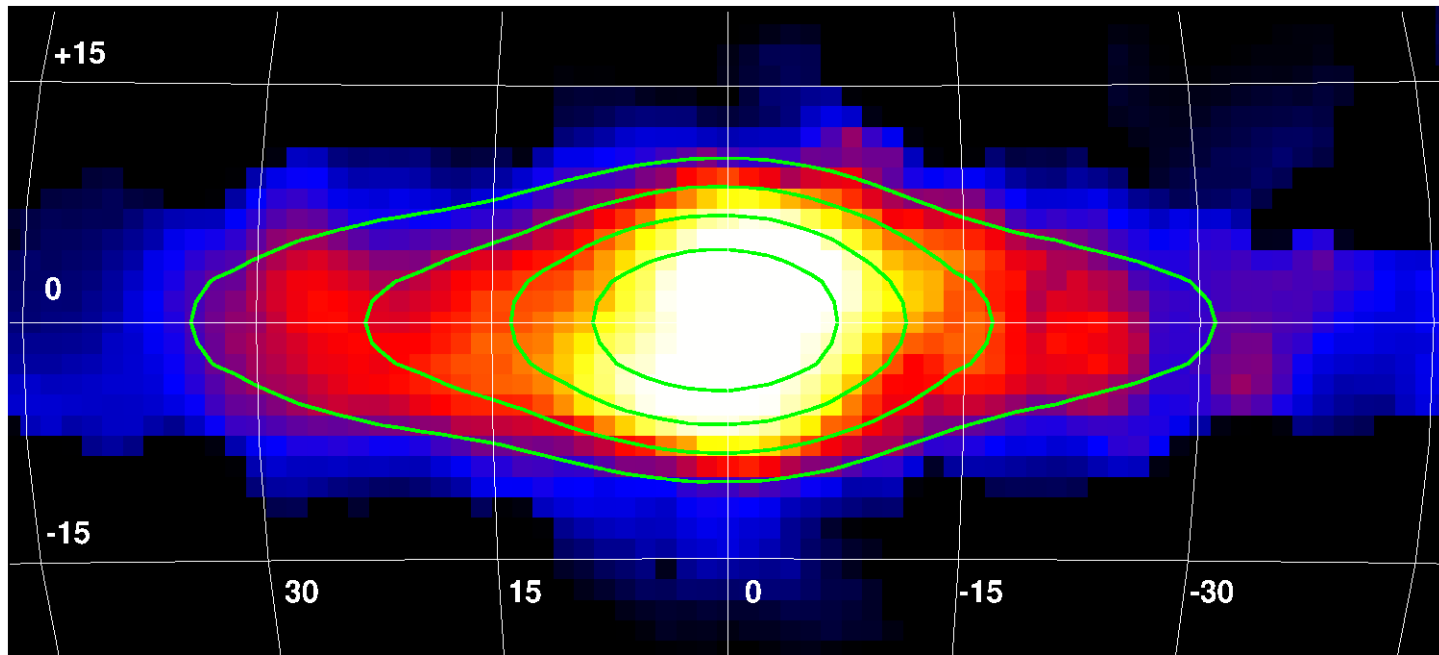
Using a lightbucket technique, Lebrun et al (2004) showed that more than 80% of the total Galactic flux is due to point sources under 100 keV



*Lebrun et al. (2004)*  
*Terrier et al. (2004)*

## Diffuse emission ( $E < 100$ keV) with Integral?

Using a similar lightbucket technique, Krivonos et al (2007) studied the morphology of the residual 15% of the total Galactic flux which is not resolved in point sources

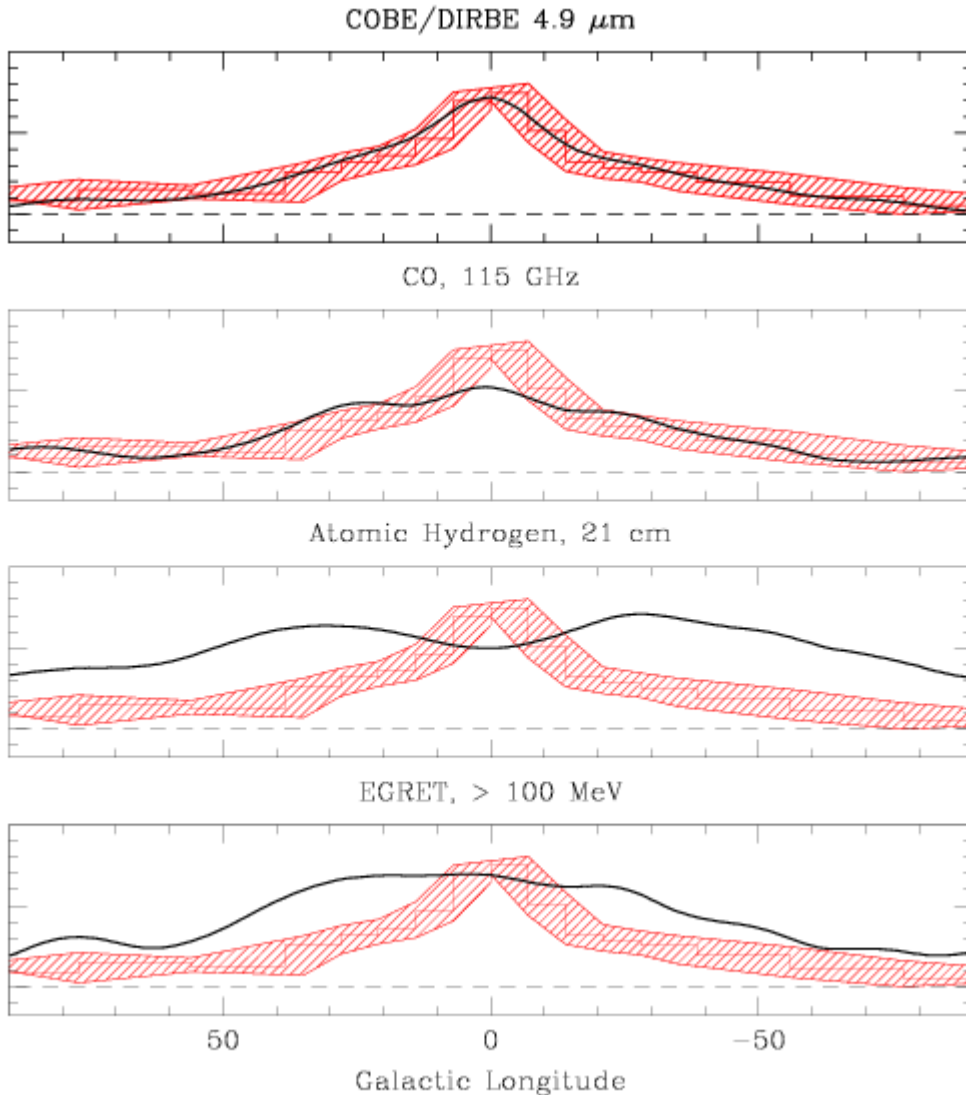


*Krivonos et al. (2007)*

The morphology is well correlated with DIRBE 4.9  $\mu\text{m}$  maps



# Diffuse emission ( $E < 100$ keV) with Integral?



ISM is not a good tracer of residual ridge emission

Hard X ray ridge emission follows stellar mass distribution

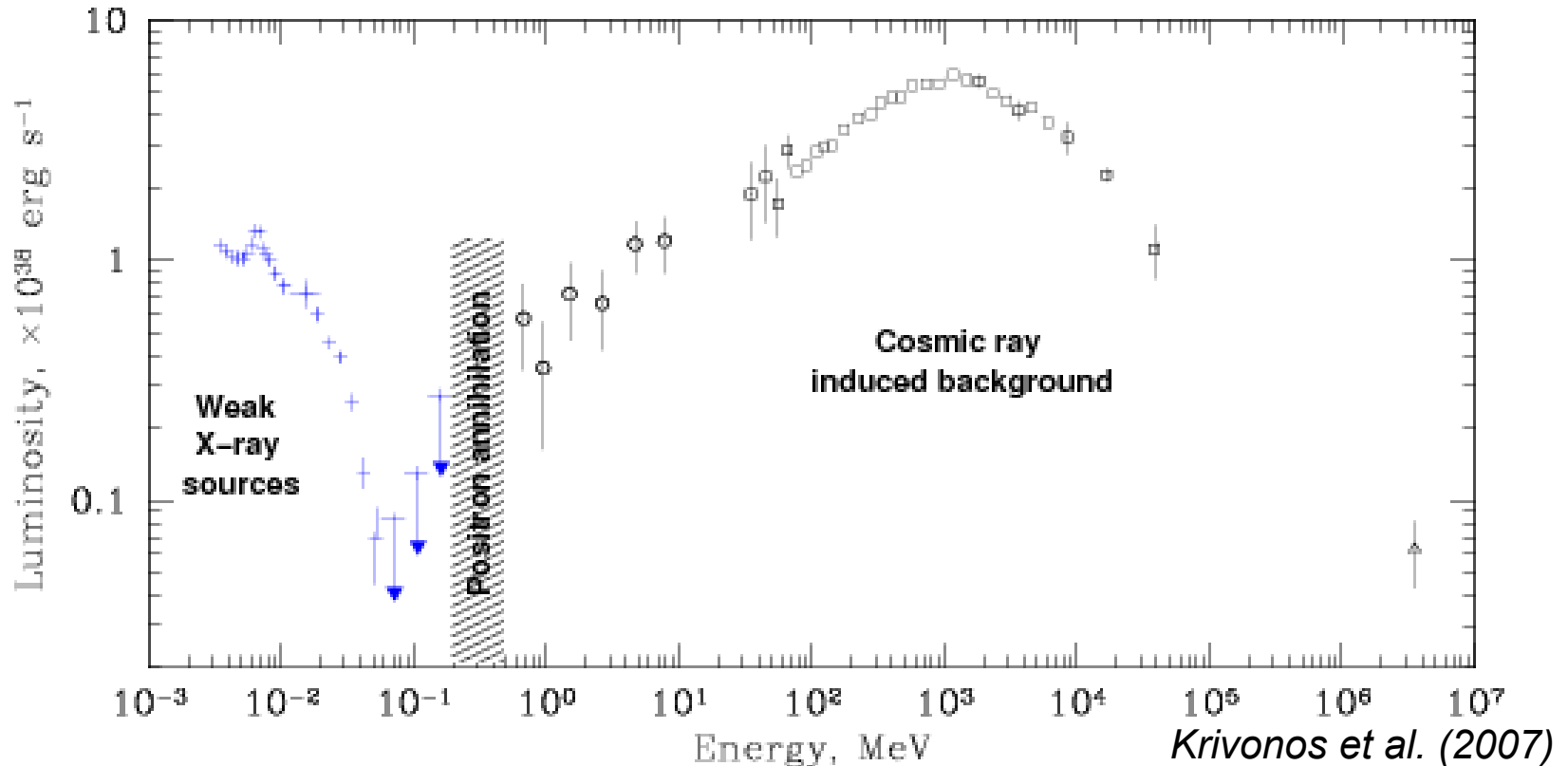
$$F_{17-60 \text{ keV}} / F_{\text{NIR}} \sim 7.5 \cdot 10^{-5}$$

Emissivity:  $10^{27}$  erg/s/ $M_{\text{sol}}$

Residual emission due to unresolved faint sources such as Cvs (similarity of the spectra)

*Krivonos et al. (2007)*

# Diffuse emission with Integral



**Low energy diffuse emission likely entirely due to point sources (most still unresolved)**

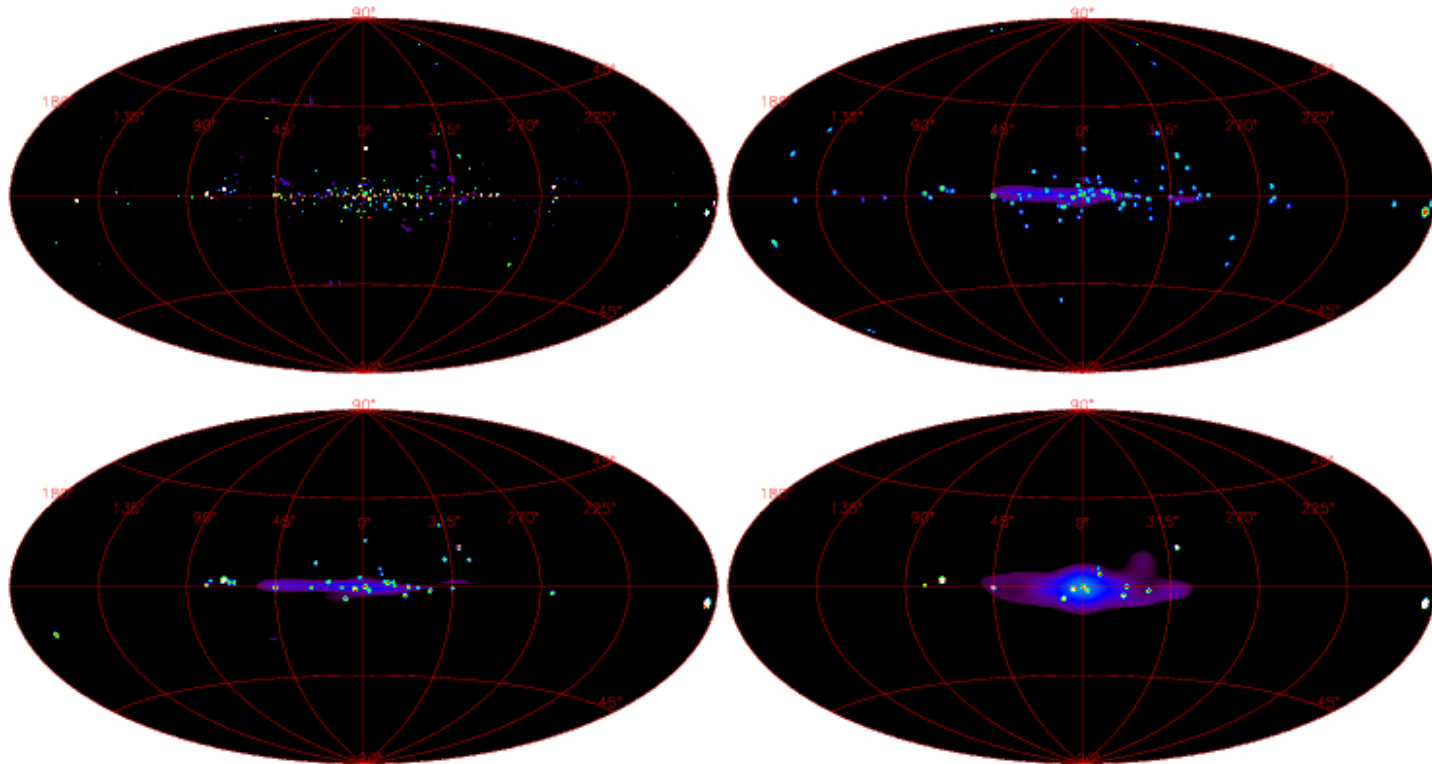
Recent result by Revnivstev et al (2009) shows that up to 90% of 6.7 keV plasma is in fact due to faint stellar population as well.

**What about diffuse emission >100 keV?**

# Diffuse emission with Integral

Analysis using SPI (more sensitive at high energies) shows that there remains a hard power law component dominant above 100 keV

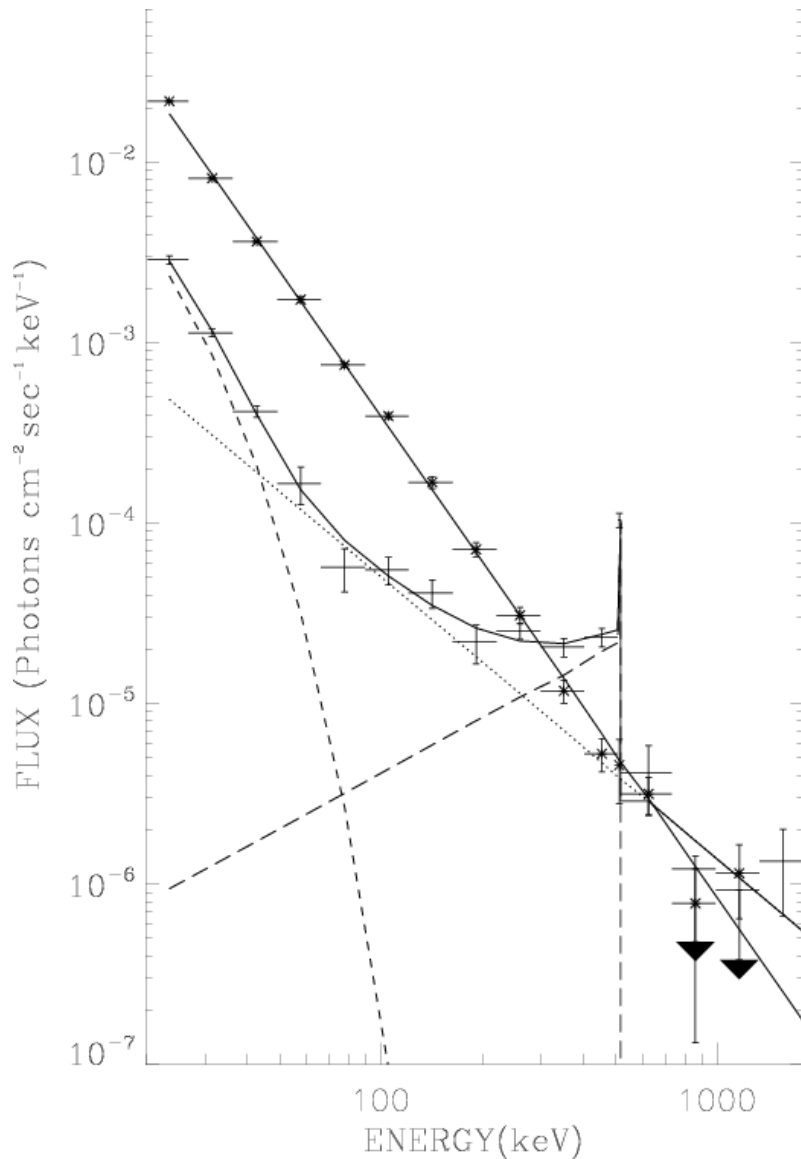
*Strong et al (2005), Bouchet et al. (2005 & 2008)*



Images obtained through a model fitting approach

*Bouchet et al. (2008)*

# Diffuse emission with Integral



$||| < 30^\circ$

Hard power law:  $\Gamma = 1.55$

Important contribution from 511 keV line and positronium

Marginally consistent with Krivonos et al non detections up to 200 keV

Origin?

*Bouchet et al. (2008)*

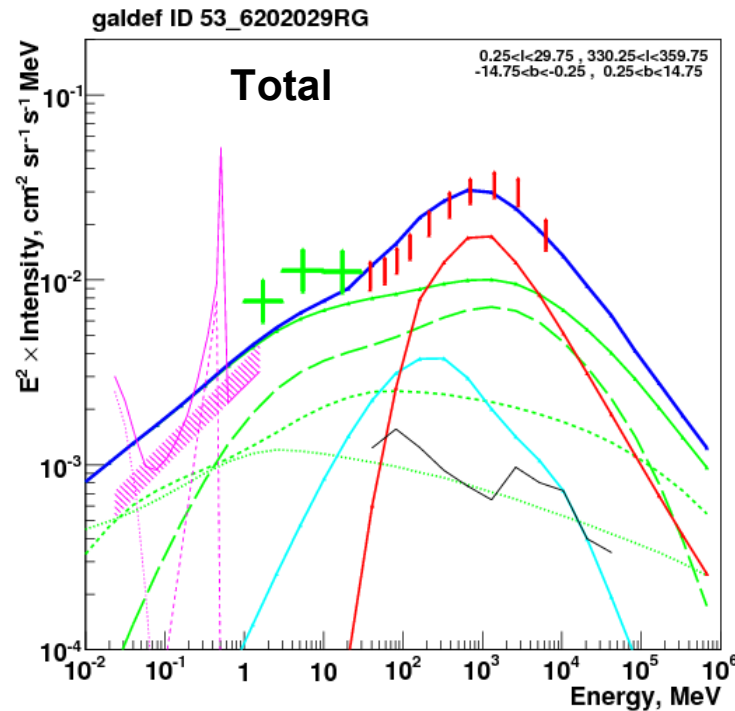
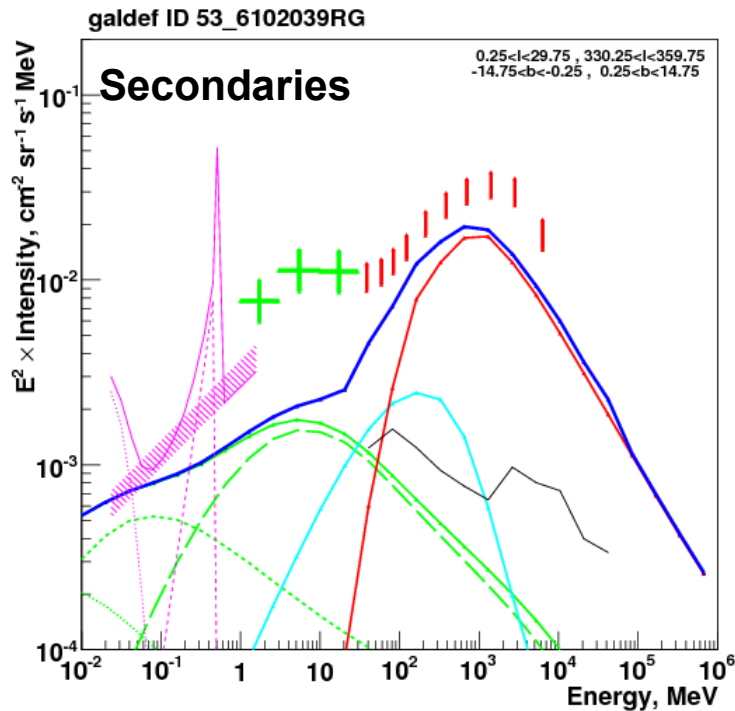
# Origin of hard power law component?

Unresolved faint and hard point sources (e.g. Pulsars and AXPs)

sub-GeV  $e^+$  and  $e^-$  IC on CMB photons (Porter et al 2008)

Secondary leptons dominant  $< 1$  GeV

Taking into account the secondaries in once optimized model overpredicts hard X-ray component



*Porter et al. (2008)*



# Origin of hard power law component?

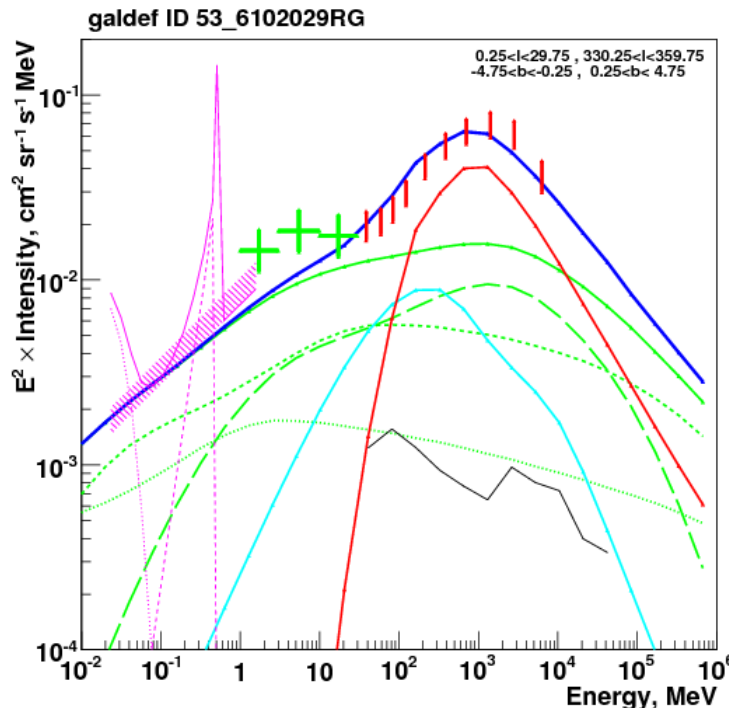
Origin of the discrepancy?

So called optimized model is no longer valid since Fermi result of the absence of GeV excess

Primary electron source spectrum < a few GeV

Latitude distribution of the electrons w.r.t. SPI measurements

$|b| < 5^\circ$



*Porter et al. (2008)*

# 511 keV emission

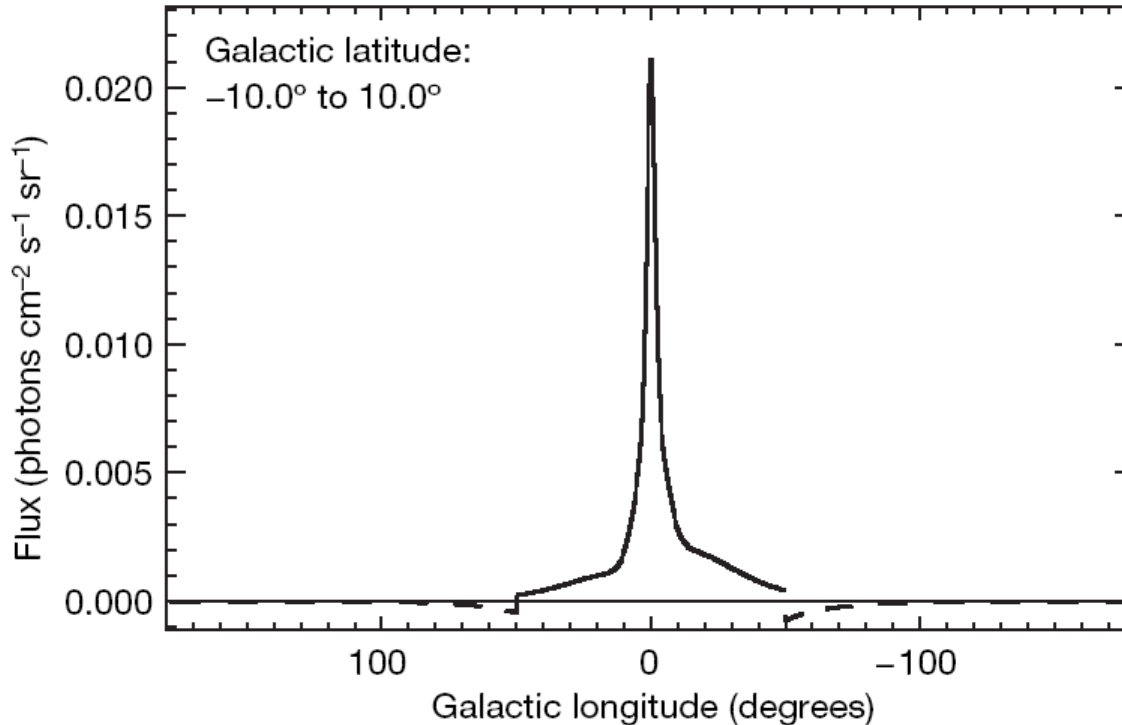
Flux of  $\sim 10^{-3}$  ph/cm<sup>2</sup>/s in 511 keV line  $\rightarrow 10^{43}$  s<sup>-1</sup> annihilations at GC distance

*Leventhal et al (1978), Kinzer et al. (2001), Knödelseder et al (2005)*

Distribution 9° (FWHM) gaussian profile around Galactic Centre. Origin?

A fainter contribution from the Galactic disk

(~25% of which is due to decay chain of <sup>26</sup>Al)



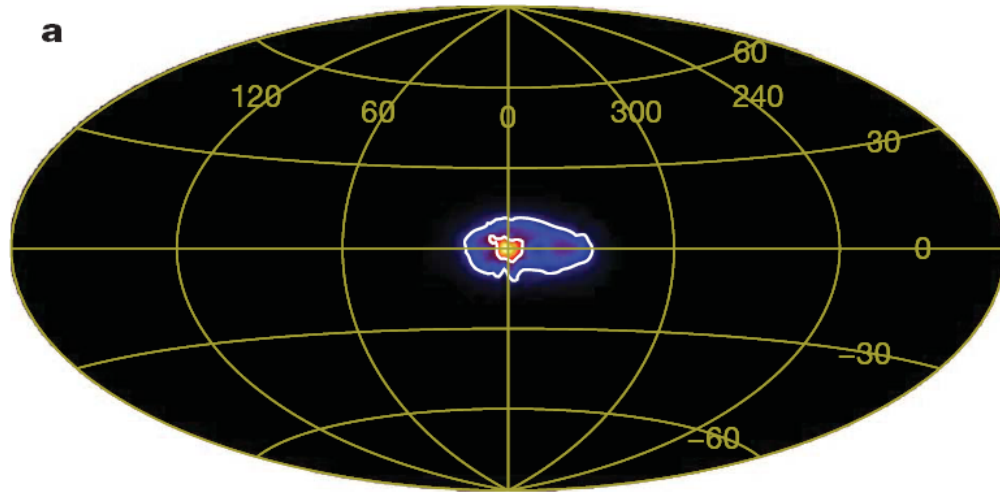
Profile  
obtained with 6  
components  
model fitting

*Weidenspointner et al.  
(2008)*

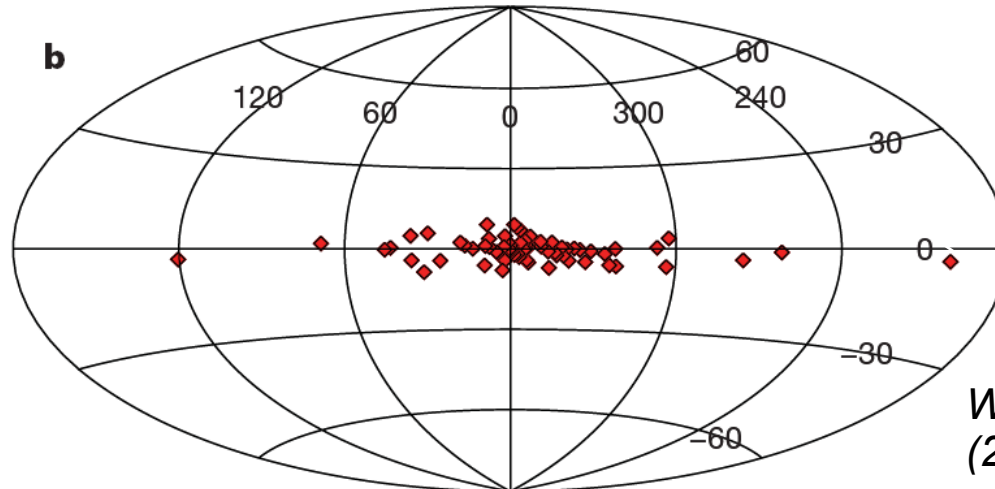
Recently, Weidenspointner et al (2008) have claimed detection of asymmetry in disk distribution

# 511 keV emission : asymmetry

Maximum entropy image of the line emission



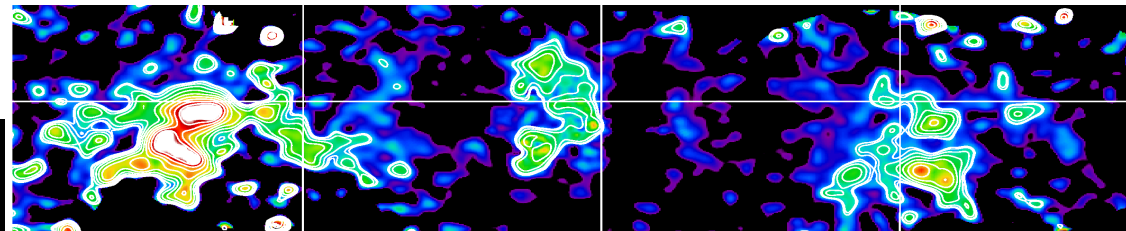
Isgri detected LMXBs  $\rightarrow$   $e^+$  origin from a few 100 hard LMXBs?



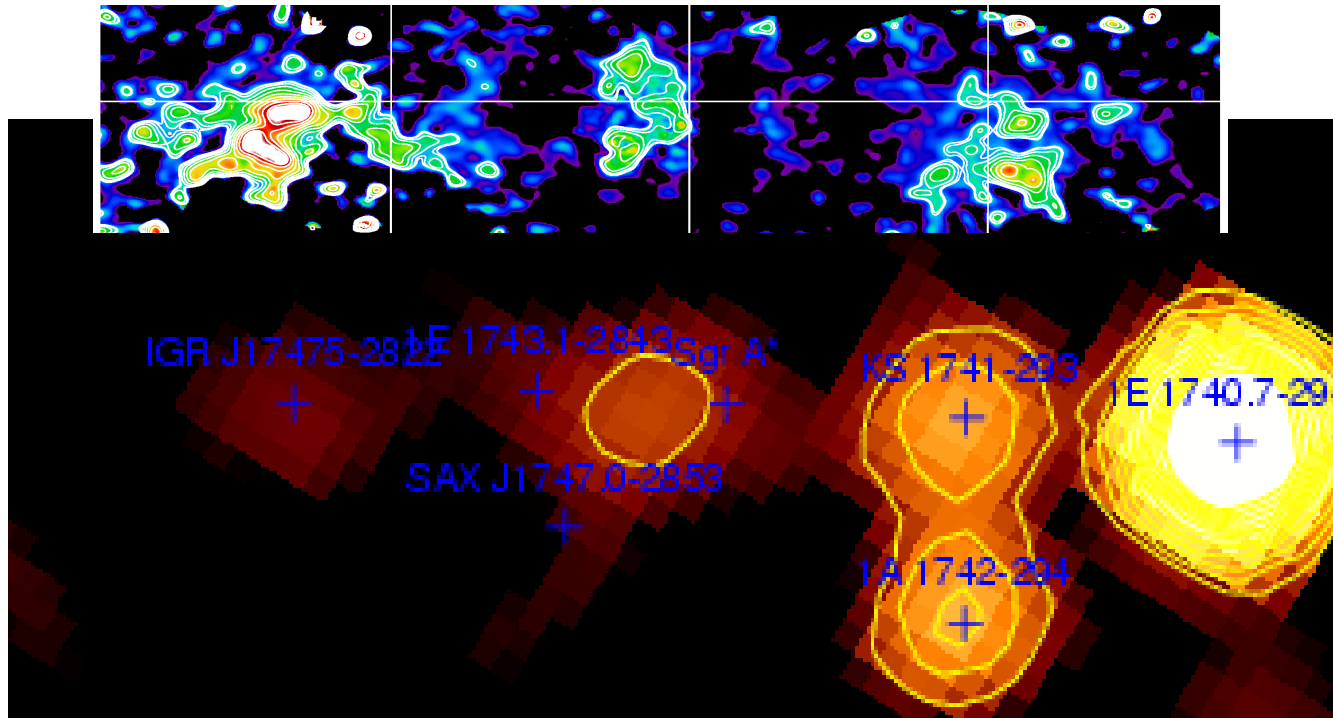
*Weidenspointner et al.  
(2008)*

# Diffuse emission from the Central Molecular Zone

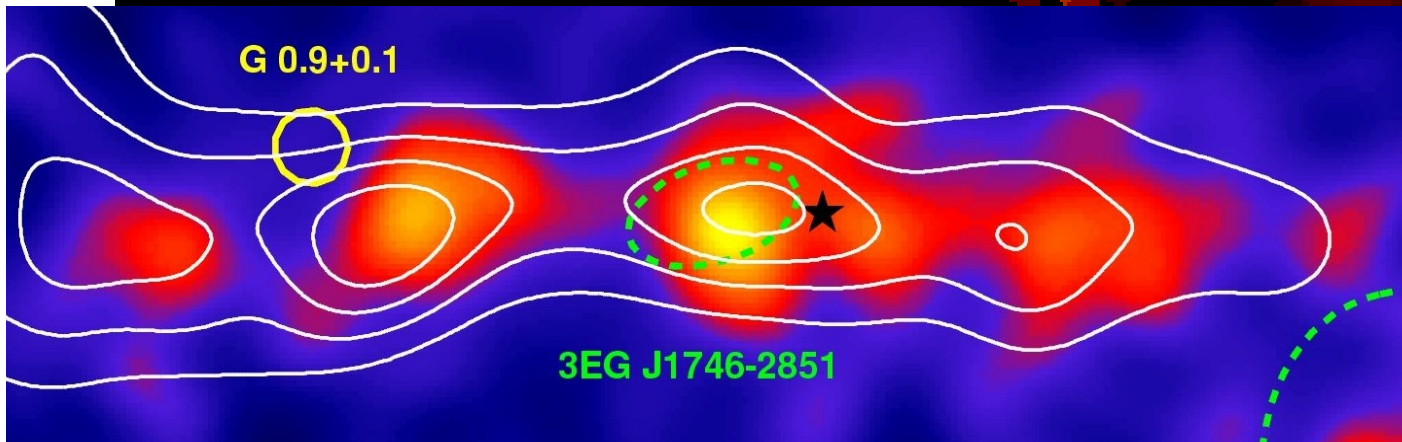
6.4 keV Ka Fe line



60-80 keV



VHE



## Diffuse emission from Sgr B2 cloud

IGR J17475-2822 detected at more than  $50 \sigma$

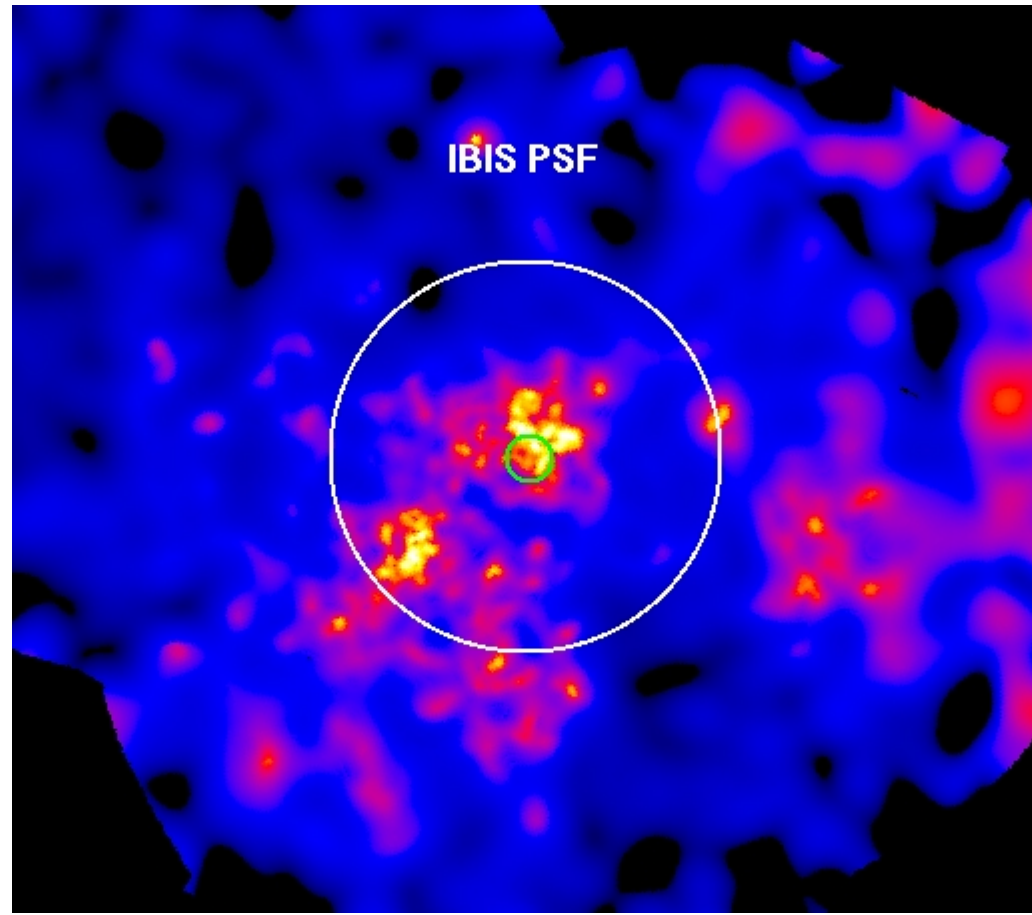
Measured 20 -100 keV flux:  $F = 2.4 \cdot 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$

$$\gg L_{\gamma} = 2 \cdot 10^{35} \text{ erg/s}$$

Fitted position in good agreement  
with Sgr B2 cloud

IBIS PSF encompasses also  
nearby M0.74-0.09 cloud

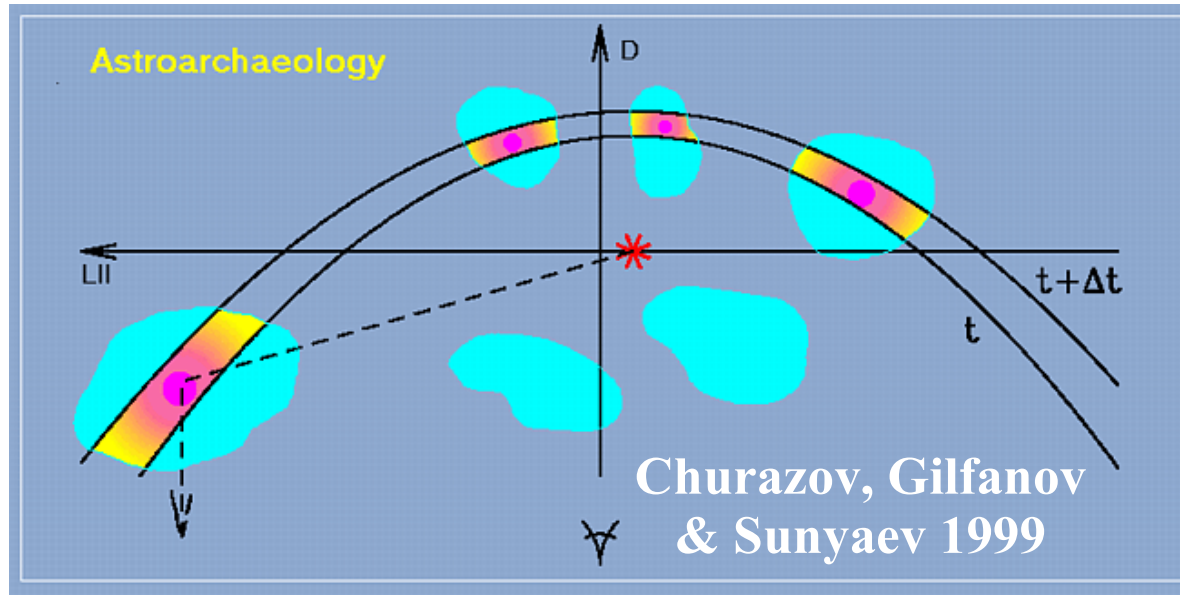
—  
Point sources in the vicinity are too  
faint to explain the Isgri source





# Origin of diffuse emission from CMZ?

Fluorescence and Compton scattering of a very bright nearby source  
*e.g. Churazov et al (1999), Murakami et al (2000)*



At  $<10\text{pc}$  distance,  $10^{37}$  erg/s flare  $\sim 10$  yr ago is required to account for measured luminosity

No such source in the vicinity of Sgr B2

At  $100\text{pc}$  distance,  $10^{39}$  erg/s flare  $\sim 300$  yr ago is required to account for measured luminosity

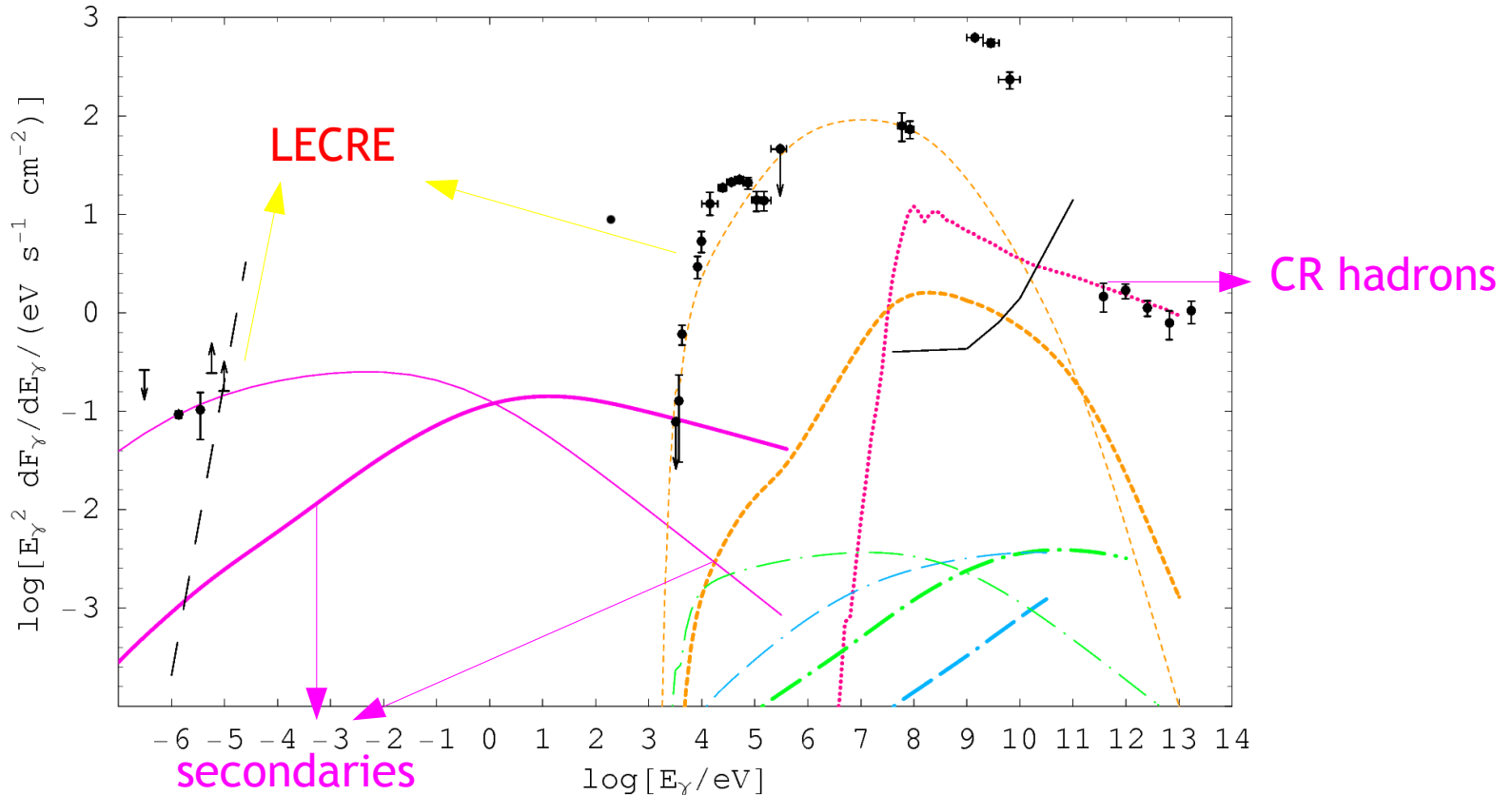
Was Sgr A\* more active than today? (6 order of magnitude increase)

# Origin of diffuse emission from the CMZ?

Intense low energy cosmic-rays electrons (LECRE)

*Valinia et al (2000)*

- Fe Ka line EW too small
- Required e- luminosity comparable to cloud bolometric luminosity because of large Coulomb losses



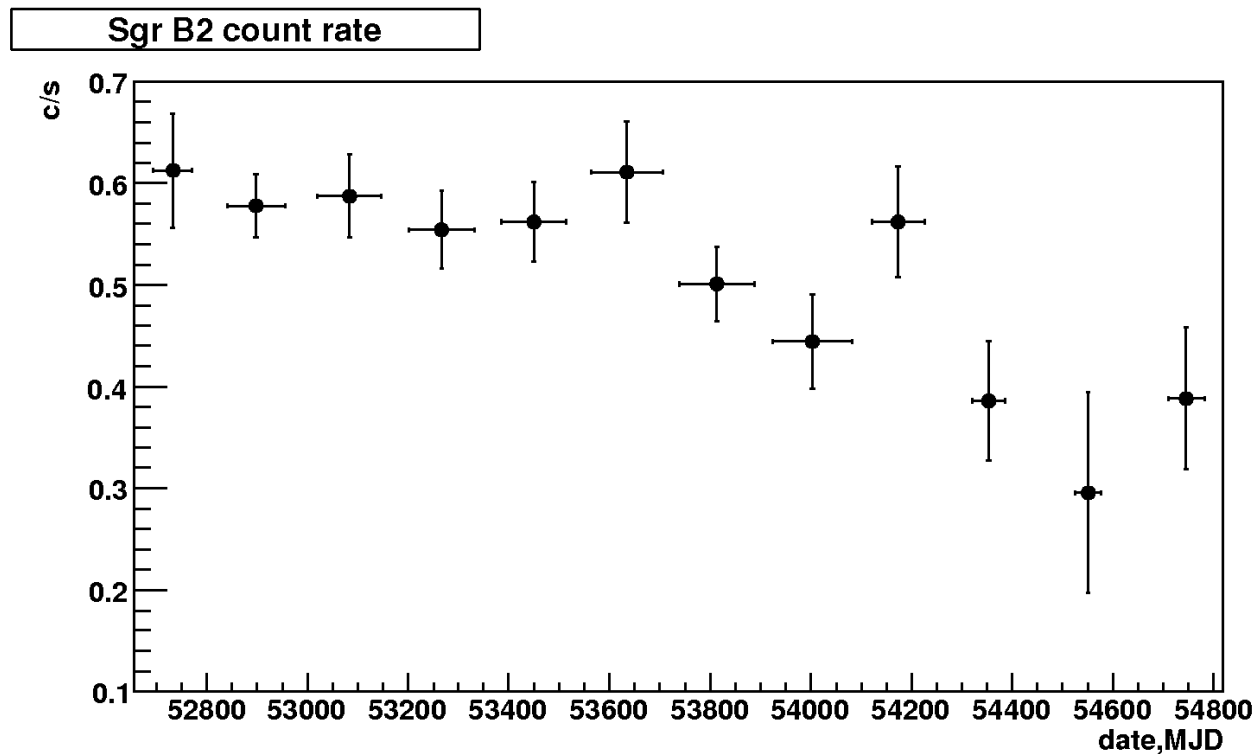
*Crocker et al, (2007)*

# Diffuse emission from the Central Molecular Zone

GMC Sgr B2: light curve: 6 years of deep monitoring

Flux is not stable

Linear flux decay preferred at the  $4\sigma$  level: typical time scale  $\sim 20$  yrs



## On the future of Integral

Instruments are still performing well:

SPI: 16 Ge detectors still working on SPI

ISGRI: <1000 noisy pixels out of 16000

gain decrease by ~ 15%

CR Background has increased significantly,

Solar cycle should decrease this contribution but there is some delay...

Mission extension:

OK till end 2010

Budget up to 2012

Discussion on possible extension in september

Last AO first round results are out:

it is possible to ask for data rights for sources in the FoV of key program observations

## Integral AO-7: Key programmes

First round of observation proposals selection has been performed:

~20 large programmes (>1 Ms) to be performed from Oct 09- Dec 10

Among these some dedicated or possibly relevant to diffuse emission studies:

- Probing relativistic electrons in the Galaxy and its halo (*Strong*)
- INTEGRAL monitoring of the Galactic Bulge region (*Kuulkers*)
- Confirming the Asymmetry of the Positron Annihilation Radiation from the Inner Galactic Disk (*Weidenspointer*)
- Deep Galactic Anticentre Survey (*Ubertini*)
- Broad view on high energy Galactic background (*Sunyaev, Krivonos & Tyngakov*)
- Nucleosynthesis and positron annihilation in the Cygnus region (*Martin*)

Data rights open for these programs: Proposals to be sent before July 3<sup>rd</sup>

Documentation and complete list of pointings at:

<http://www.sciops.esa.int/index.php?project=INTEGRAL&page=AO7S>



## AO7: Probing relativistic electrons in the Galaxy and its halo (*Strong*)

Objective:

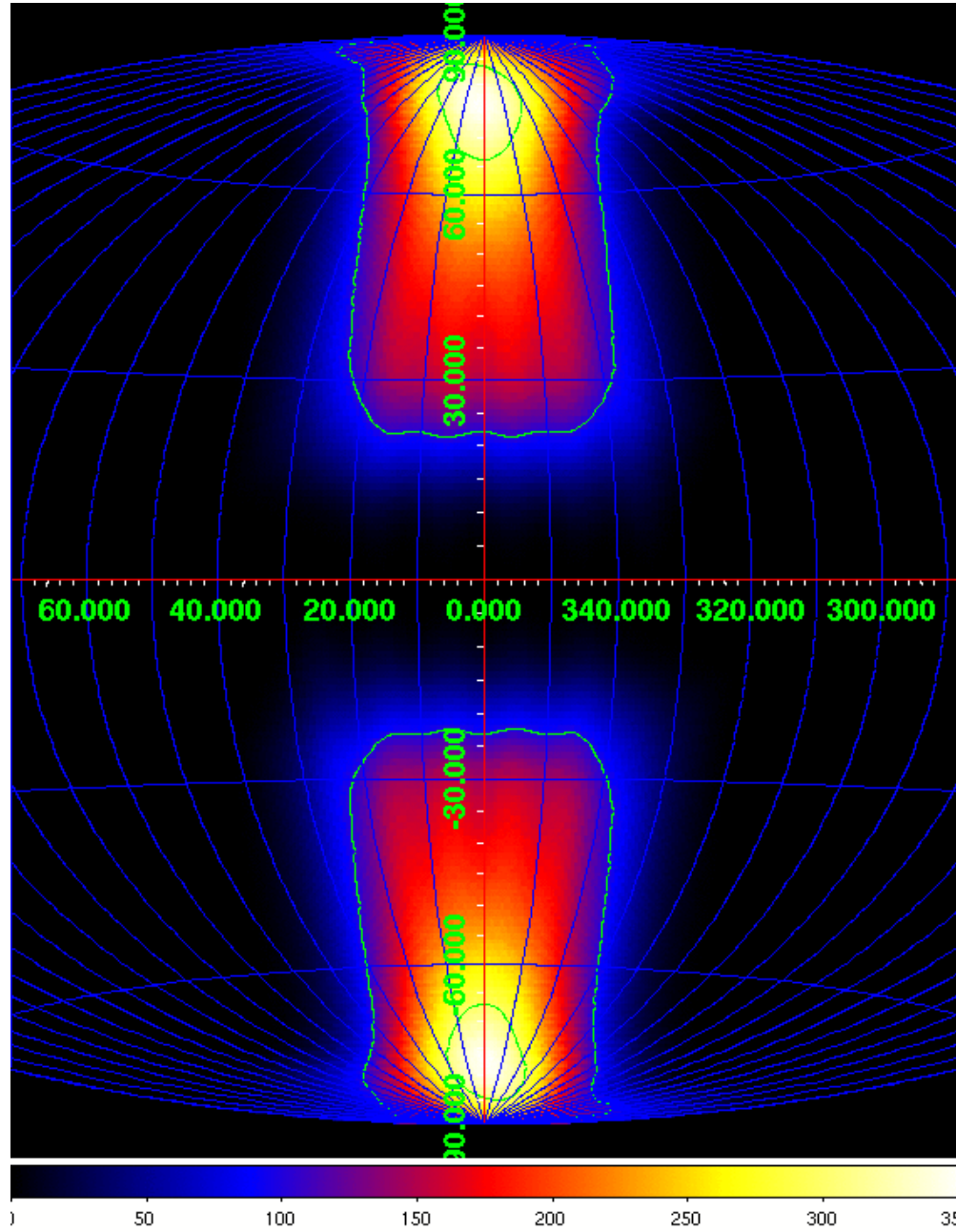
High latitude distribution of the hard power law component of diffuse emission

A probe of the distribution of cosmic-ray electrons in the Galaxy

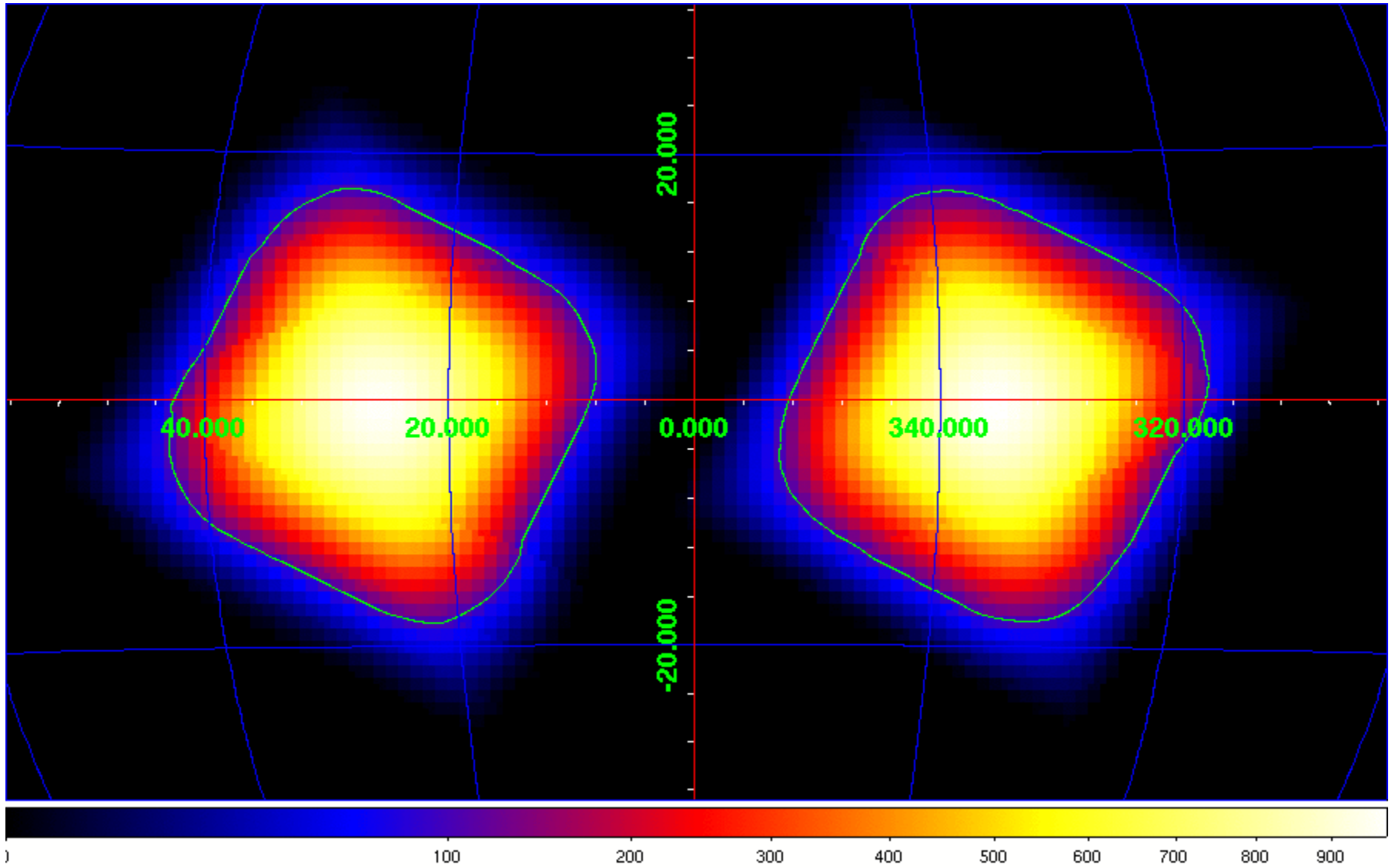
Try to solve the discrepancy with the overprediction of sub GeV secondaries IC in GALPROP

a multi-year scan covering a wide latitude range in the inner Galaxy

A link with the Fermi LAT



AO7: Confirming the Asymmetry of the Positron Annihilation Radiation from the Inner Galactic Disk (*Weidenspointner*)



# Conclusions

Integral (along with other instruments) has completely changed the picture of the diffuse emission in the hard X-ray and soft gamma-ray domain.

No soft and bright ridge emission  $<100$  keV : a collection of faint sources distributed as stars: magnetized CVs

A remaining hard ( $\Gamma=1.55$ ) power law component along the Galactic plane:

unresolved hard sources?

IC of GeV electrons on CMB photons?

$e^+/e^-$  annihilation signal distributed in the bulge + possibly asymmetric disk component

$e^+$  created by hard LMXBs?

Emission from Sgr B2 GMC in the Galactic Centre likely due to reflection from a past flare in the GC vicinity

Low energy CR probably not dominant there

Integral still doing well: propose your favorite sources in AO7 round 2!!!

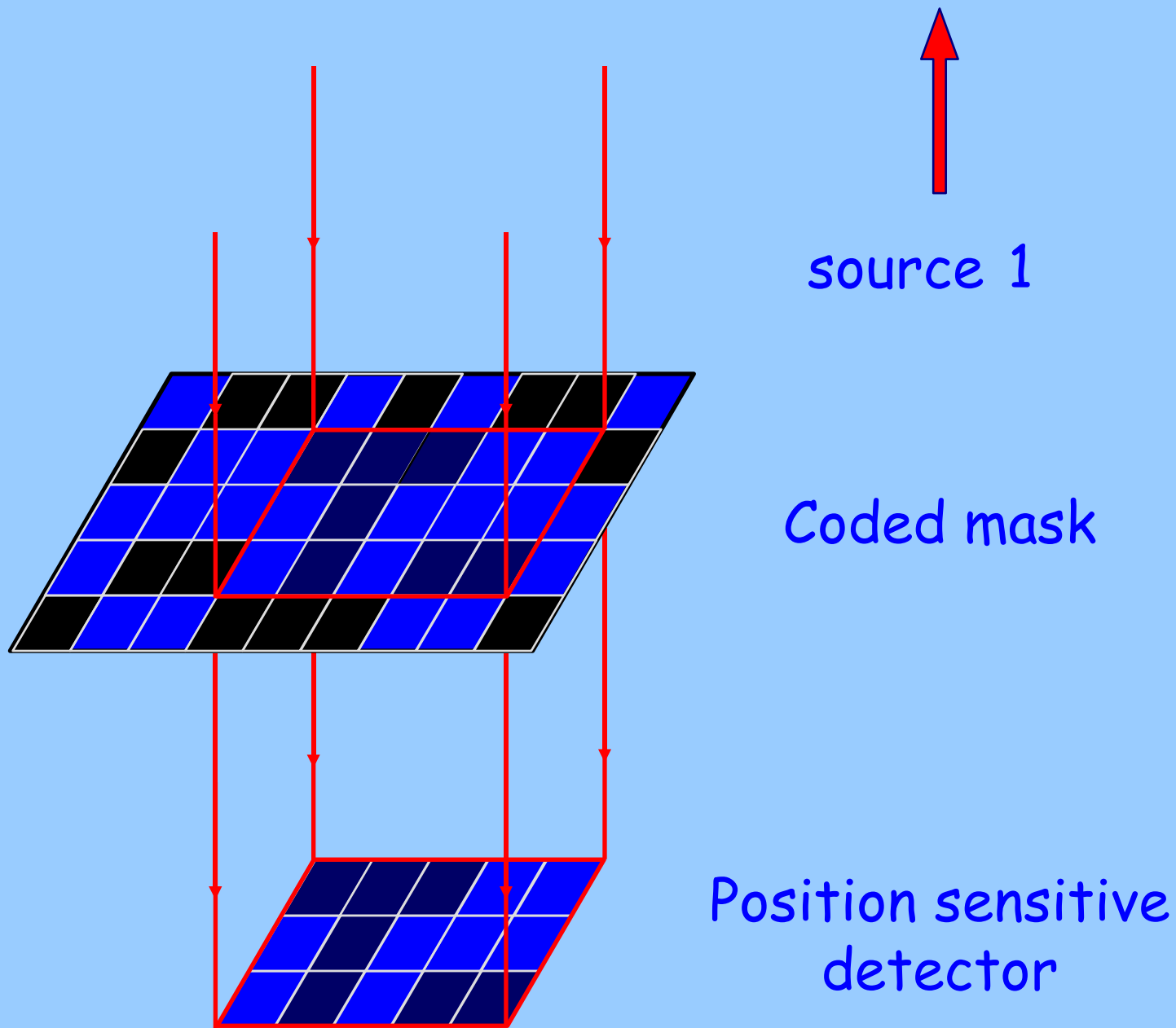


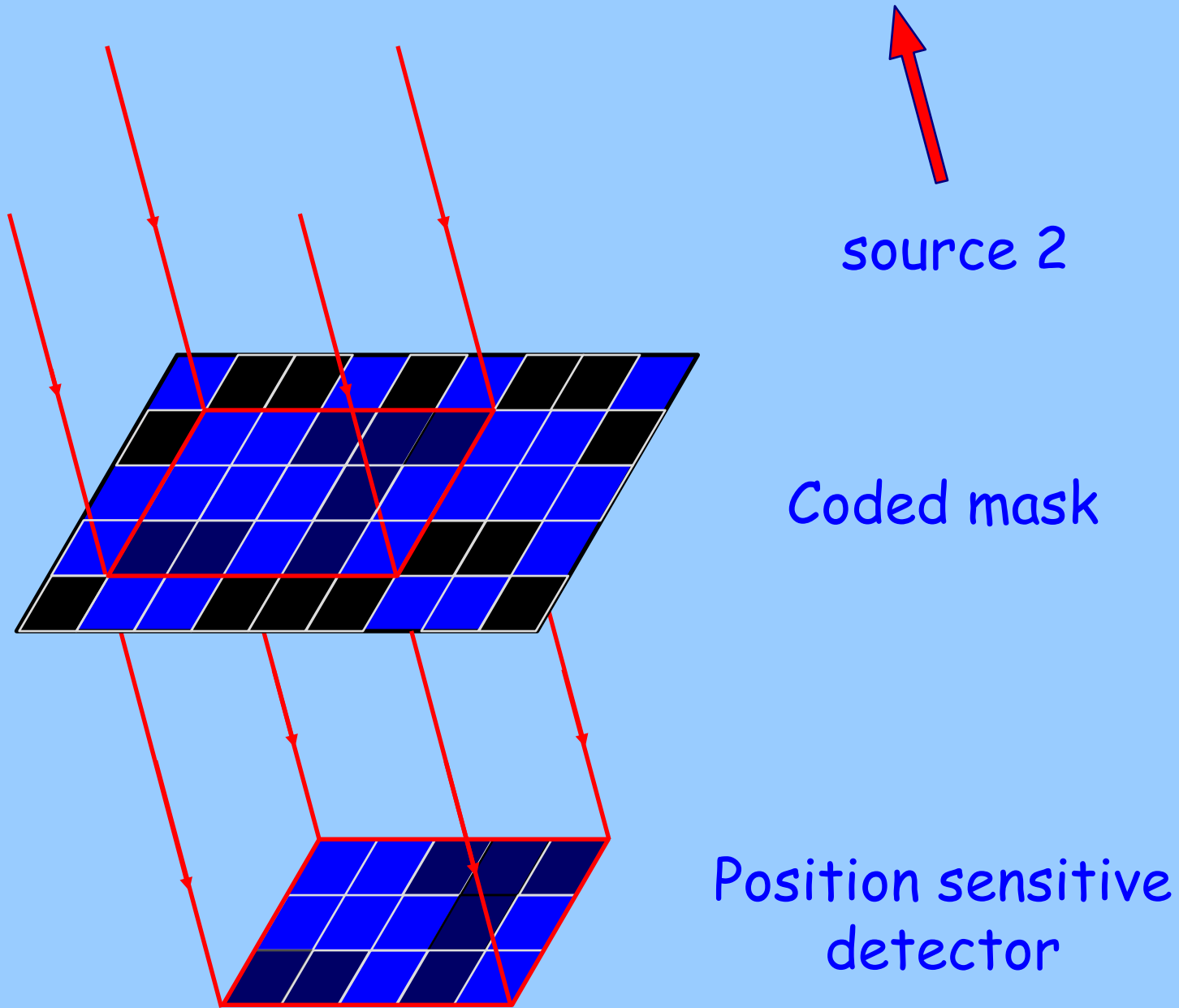
**How to measure**

**hard X-ray and soft  $\gamma$ -ray**

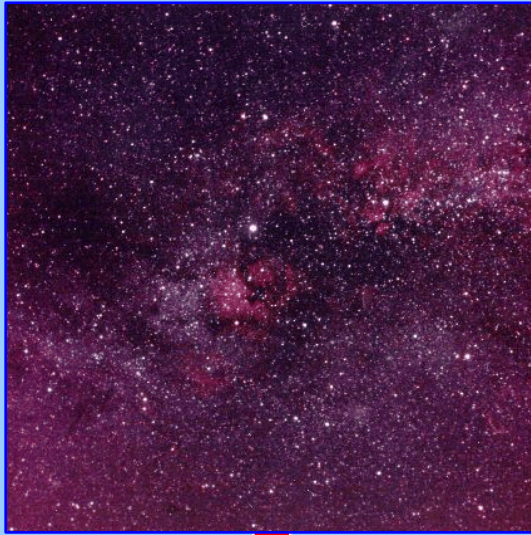
**Galactic diffuse emission?**

**Separating point sources from diffuse emission**

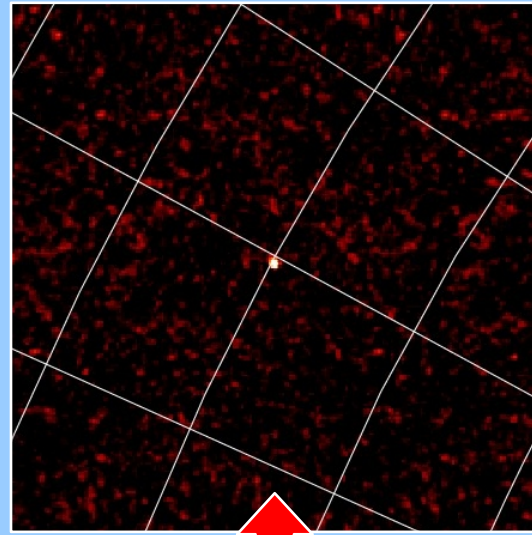
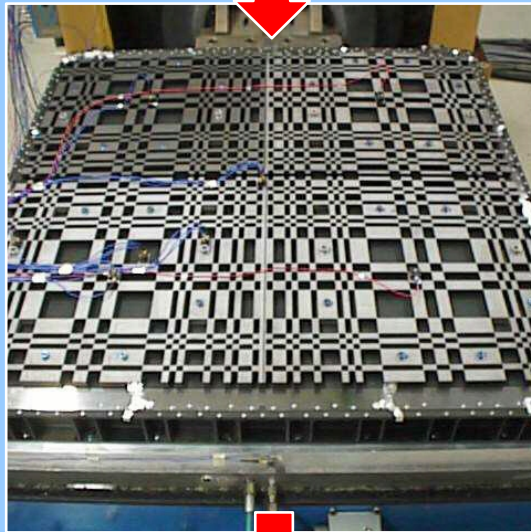




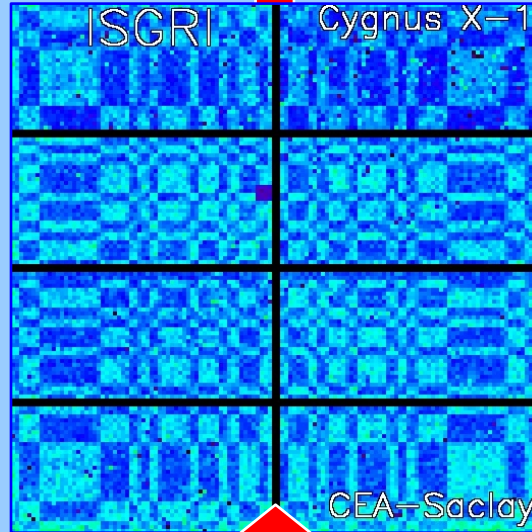




observation



deconvolution



transmission

# Diffuse emission with a coded mask instrument?

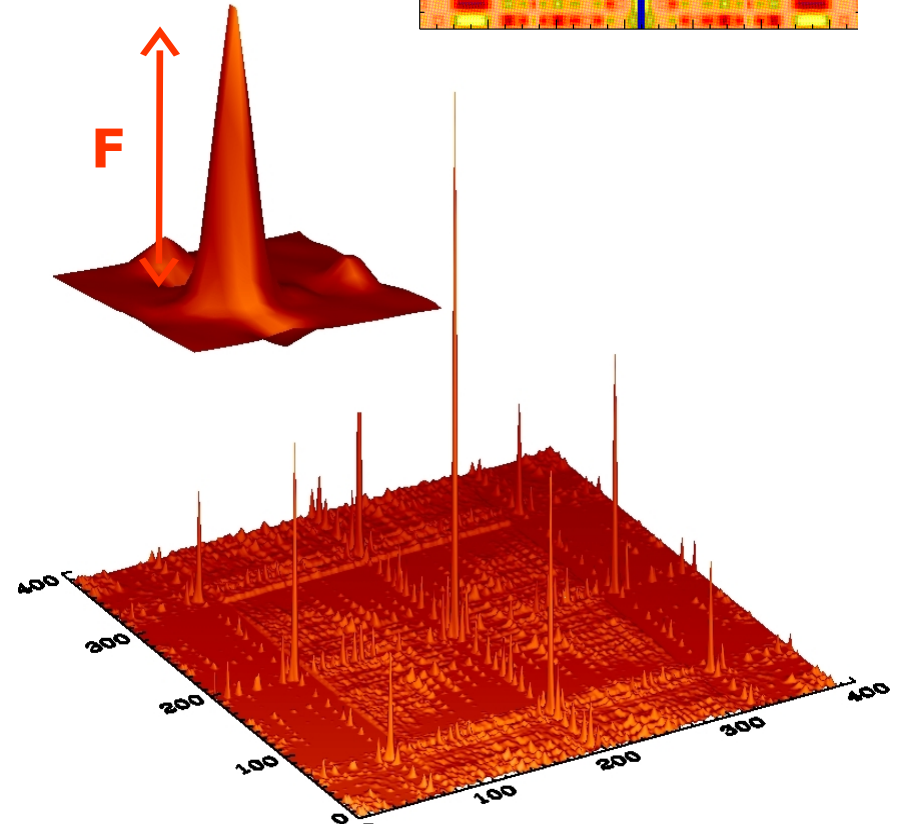
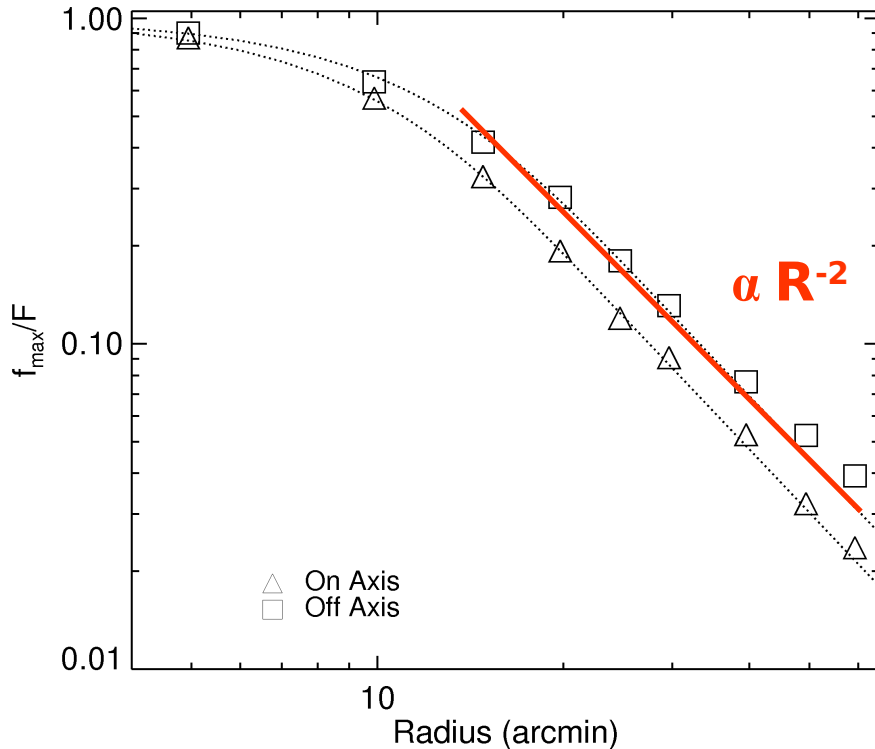
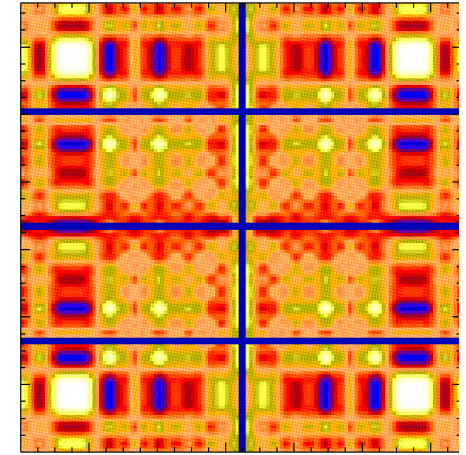
Objectives:

**resolve point sources component**

**Image residual diffuse emission**

Coded mask imaging process suppresses structures larger than the PSF

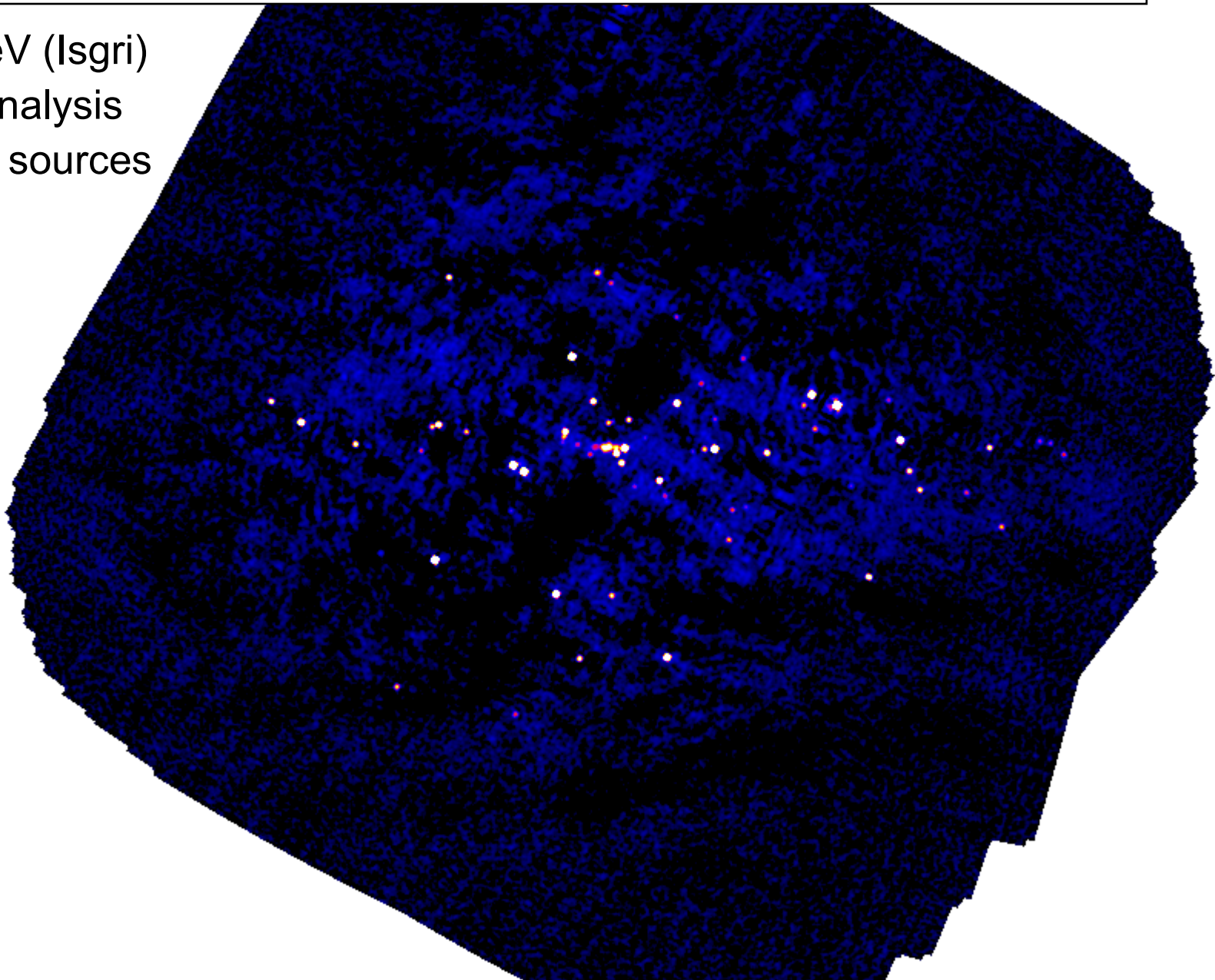
(12' for IBIS, 2.6° for SPI)





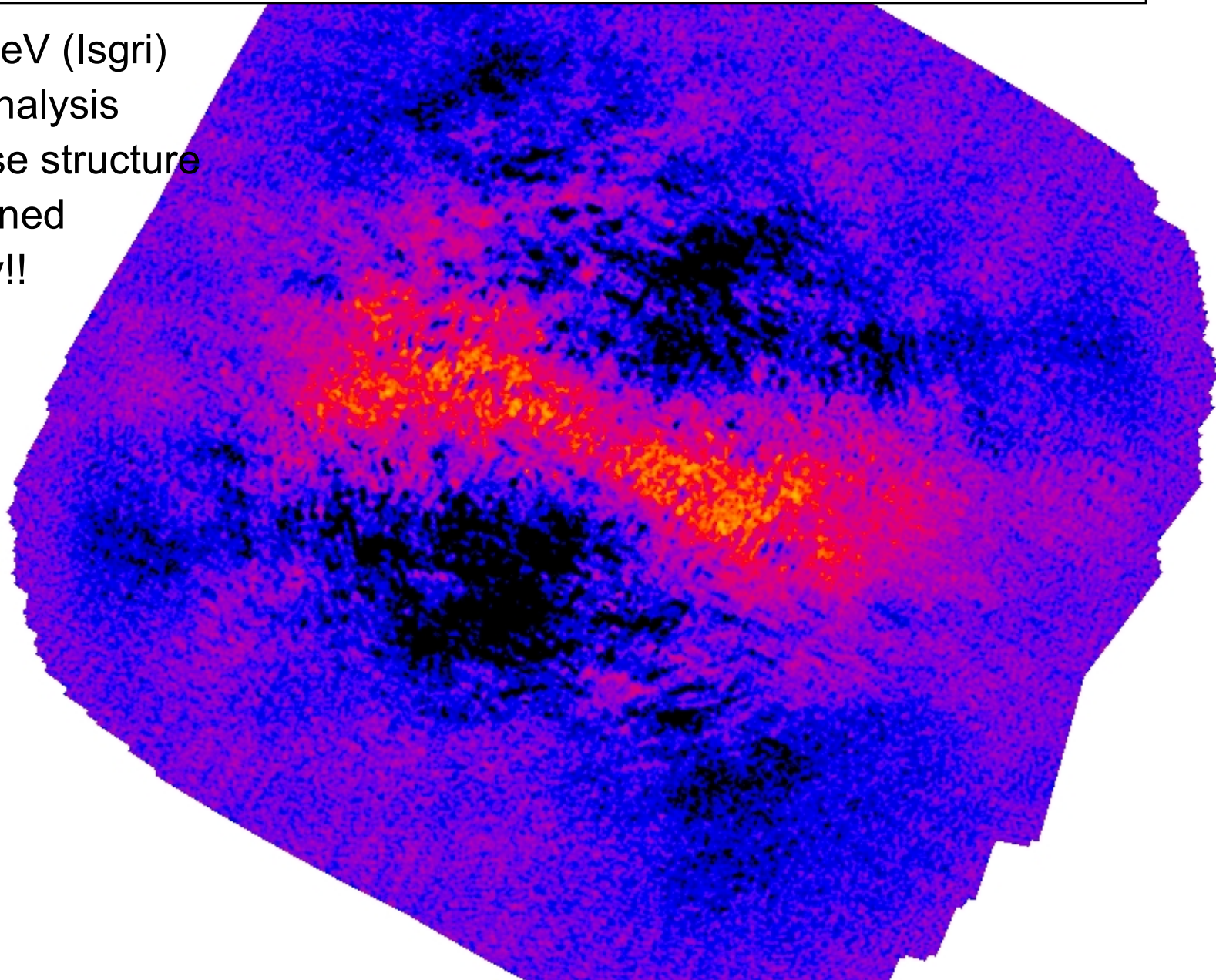
## Diffuse emission with a coded mask instrument?

GC ~ 25 keV (Isgri)  
Standard analysis  
Many point sources  
Diffuse?



## Diffuse emission with a coded mask instrument?

GC > 200 keV (Isgri)  
Standard analysis  
Large diffuse structure  
But not aligned  
with Galaxy!!



# Diffuse emission with a coded mask instrument?

## Objectives:

resolve point sources component

Image residual diffuse emission

Coded mask imaging process suppresses structures larger than the PSF  
(12' for IBIS, 2.6° for SPI)

## Several techniques to overcome this difficulty:

### **Lighbucket:**

*Lebrun et al (2004), Krivonos et al (2007)*

Use instrument as a collimator for the total flux but use its imaging capabilities to resolve point source fluxes

### **Model fitting:**

*Bouchet et al. (2005)*

Fit a diffuse model made of templates (e.g. CO & HI) plus point sources

### **Likelihood technique:**

*Bouchet et al. (2008)*

Fit diffuse fluxes in large spatial bins + point sources

### **Iterative deconvolution:**

*Knödelseder et al (2007)*

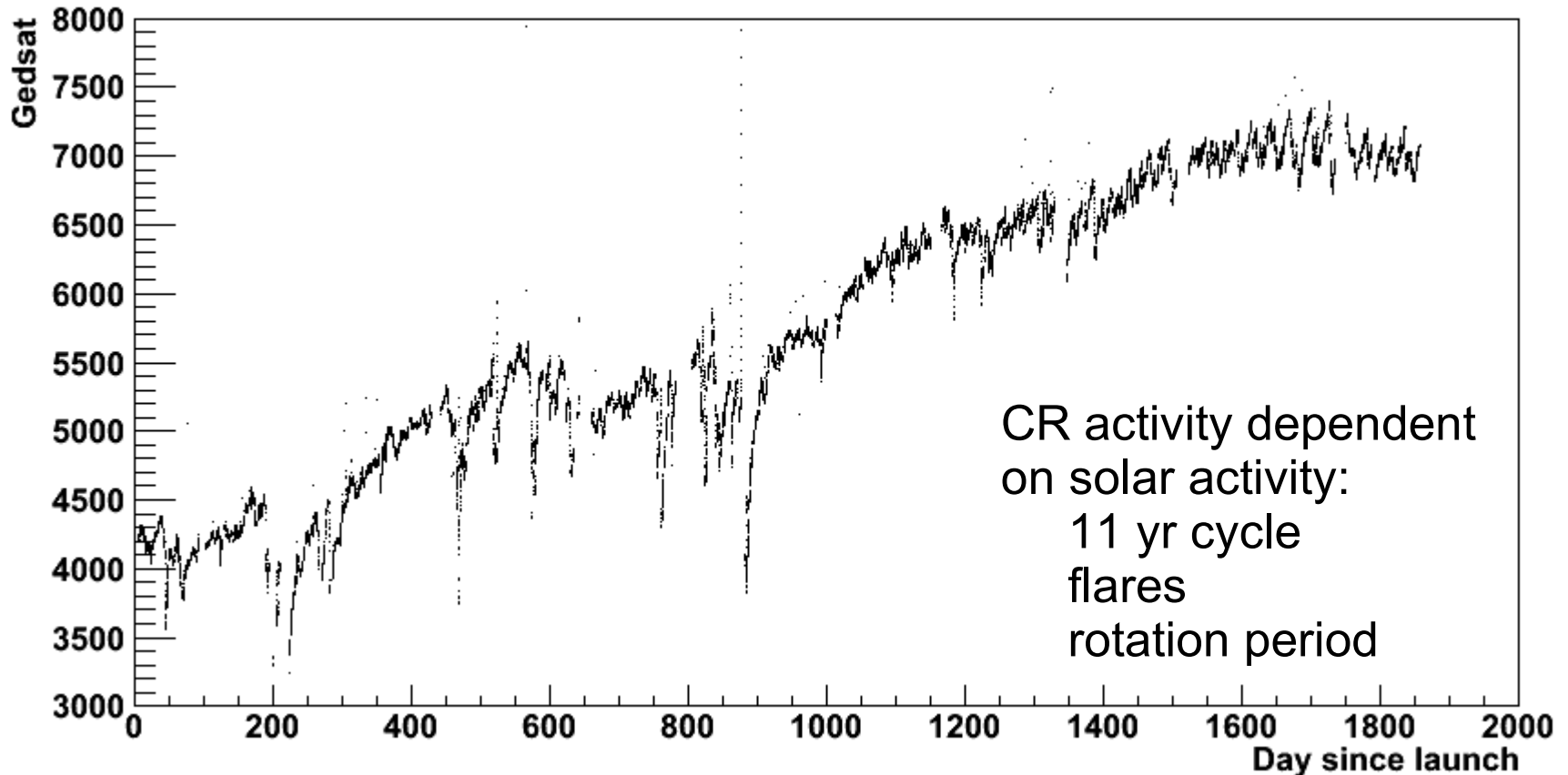
Use input source list and apply constrained model



# On background subtraction

Whatever the approach: **Background is your enemy!**

Use CR counters on board to evaluate CR activity and model the induced bkg in the detectors



# Light bucket : Using IBIS as a collimator

*Lebrun et al (2004) Terrier et al. (2004), Krivonos et al (2007)*

Compare **measured** count rate to **expected** count rate from detected sources:

- Cosmic-ray induced BKG (especially time varying BKG)
- Isotropic & constant component (Cosmic diffuse BKG + internal BKG)
- Point sources & diffuse Galactic emission

Typical algorithm:

Detect point sources

Calibrate bkg model on high latitude data

For each pointing

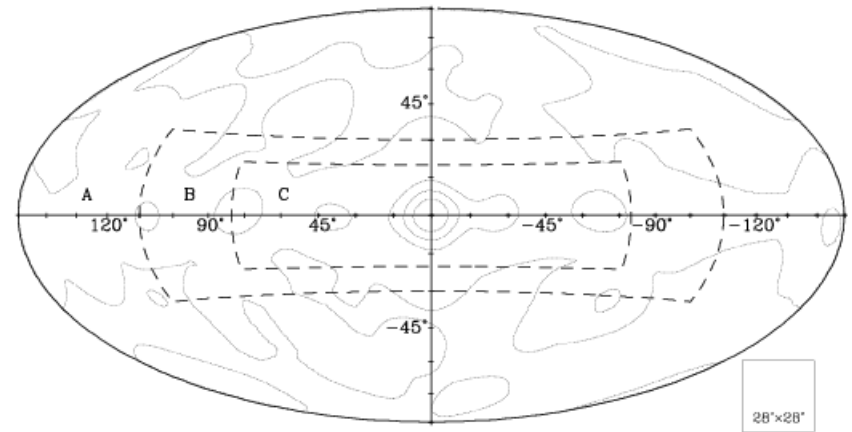
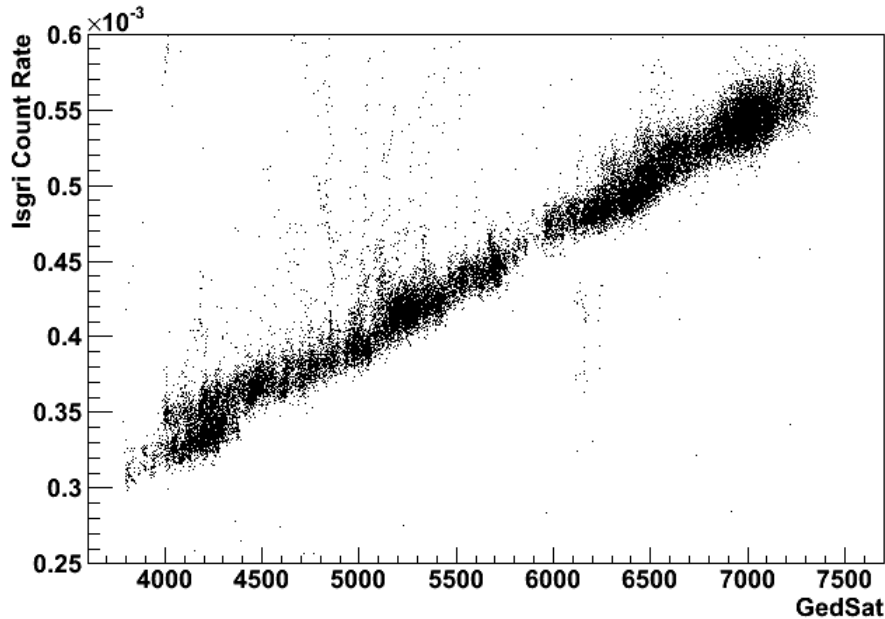
- Correct for isotropic and time varying backgrounds
- Estimate precisely source count rate in the detector
- Compute residual emission (isotropic + Galactic “diffuse”)
- Add flux to map using instrument acceptance: resolution = FoV size

Difficulties:

Number of parameters (up to 120 sources in foV)

Poor angular resolution

# Light bucket: background subtraction



Determine detector count rate correlation with CR

calibration using high latitude observations  $|b| > 30^\circ$  (no sources, no Galactic emission)

Uncertainties in this relation limits the accuracy of flux correction

Allows to evaluate isotropic (CXB) & constant BKG (activation in satellite)

# Light bucket: detecting sources

Apply “standard” analysis techniques  
Source detection algorithm



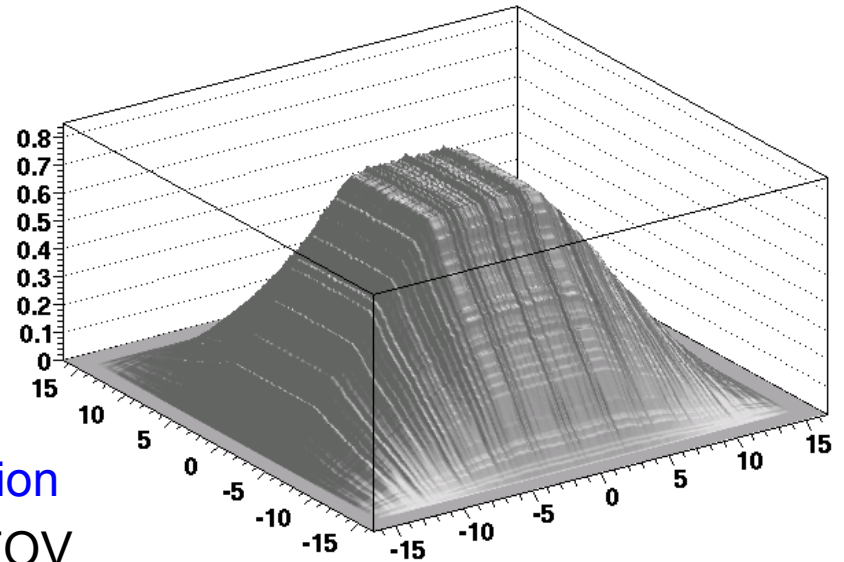


# Estimating the sources count rate

To estimate the total point sources flux through 'ISGRI collimator':

For each pointing:

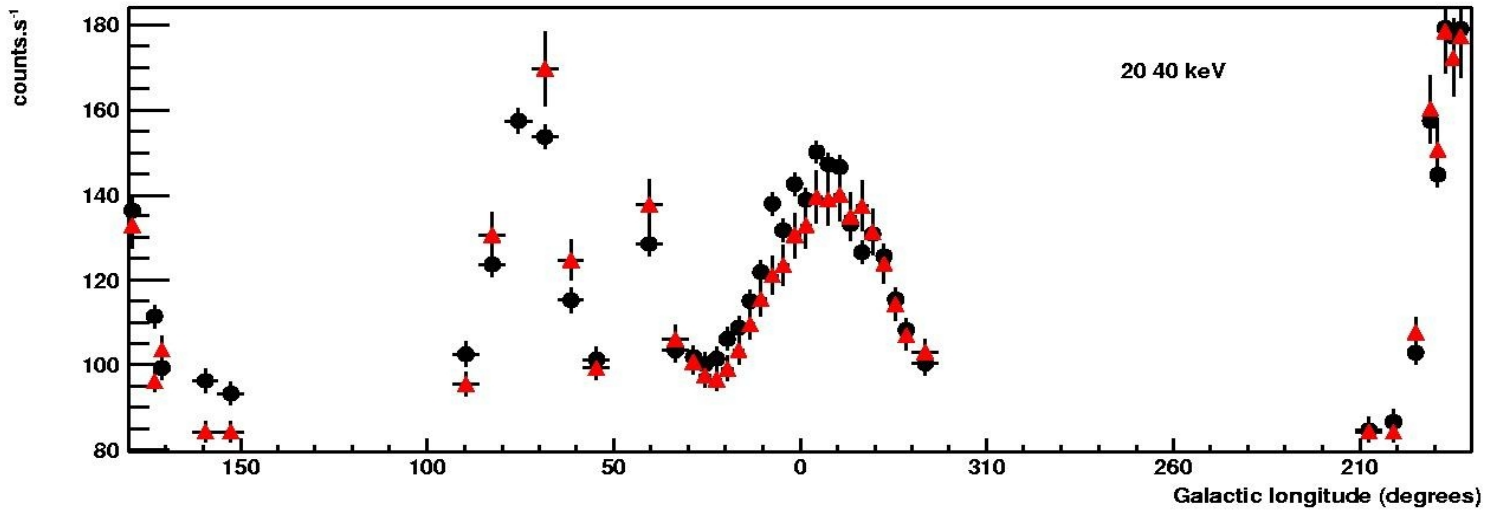
- For all detected sources
  - Use the **estimated count rate through imagery**
  - **Correct for acceptance & absorption** using the source position in the FOV
- Sum all sources count rates
- **Normalize total flux using crab observations** to correct for inaccuracies in imagery flux calibration



Systematics are introduced by this calibration

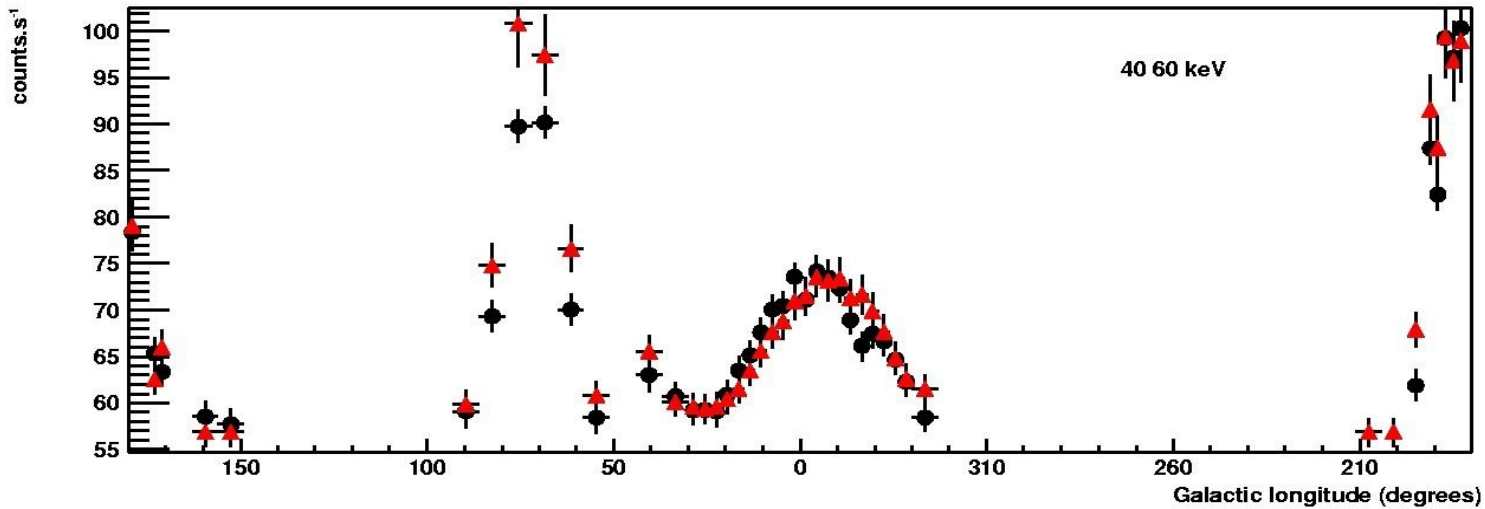
# Longitude profiles

a



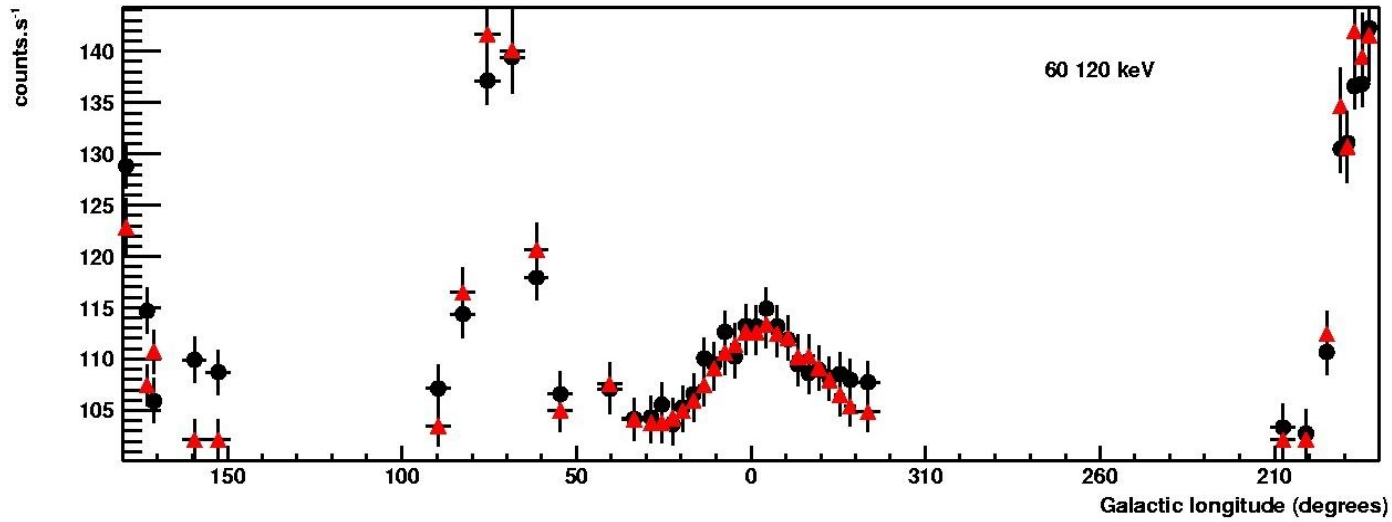
$|b| < 5^\circ$

b



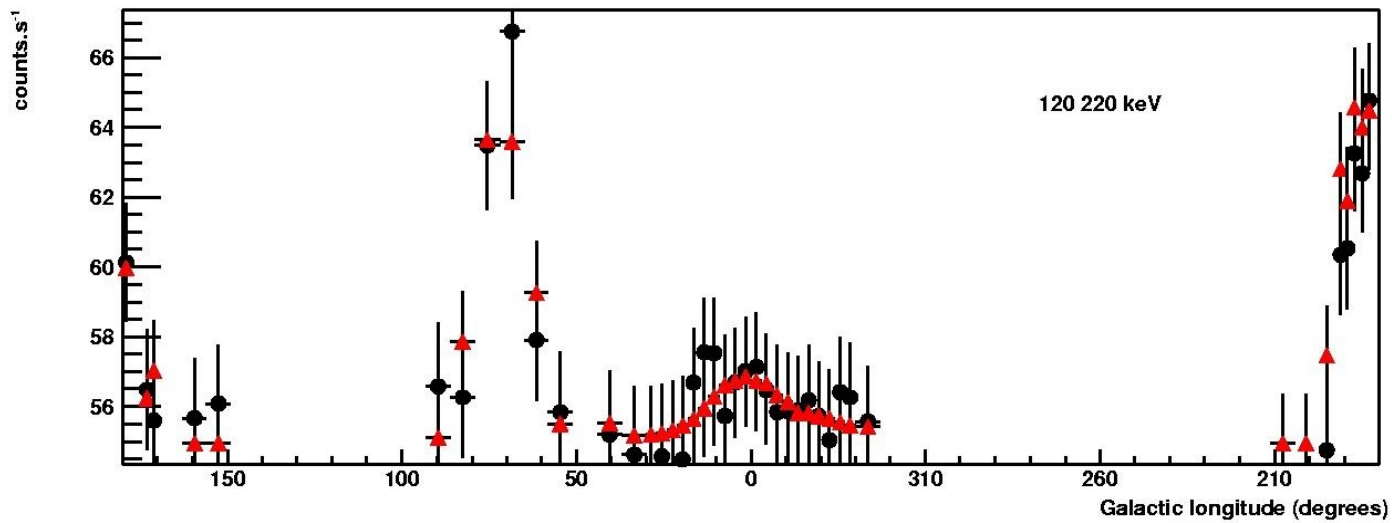
# Longitude profiles

c



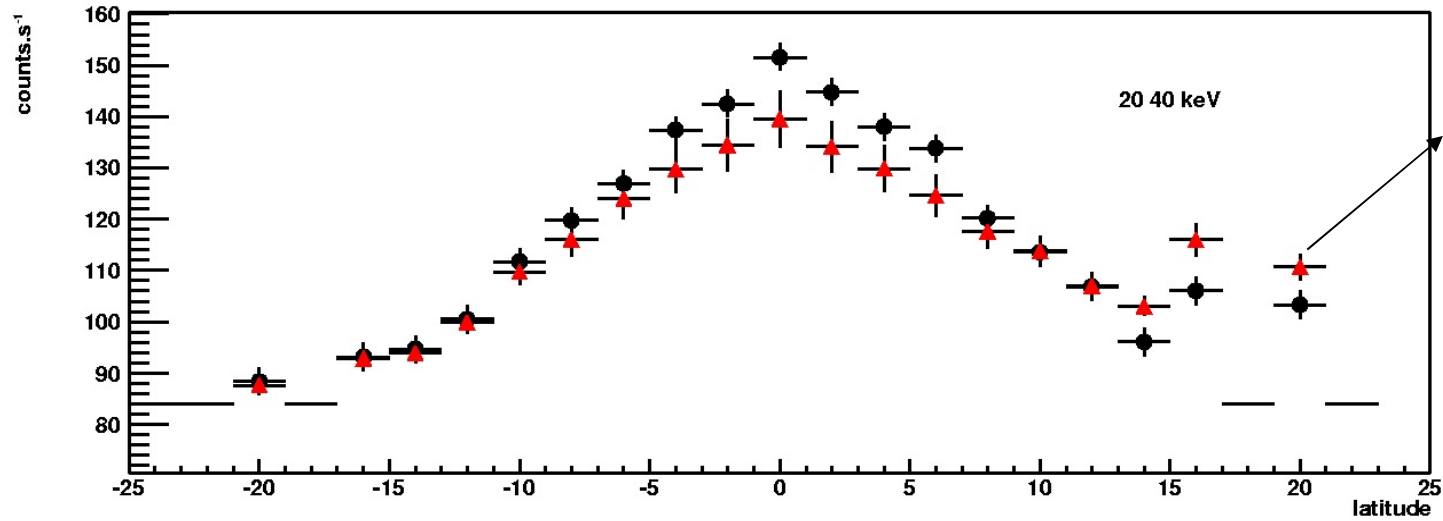
$|b| < 5^\circ$

d



# Latitude profiles

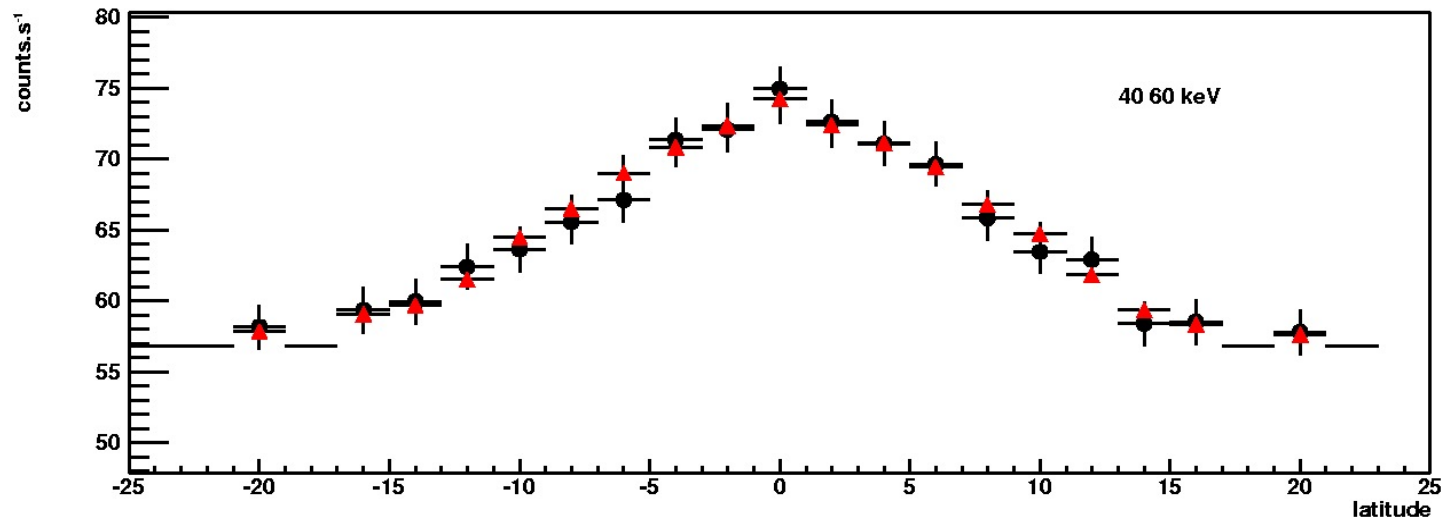
a



$||| < 20^\circ$

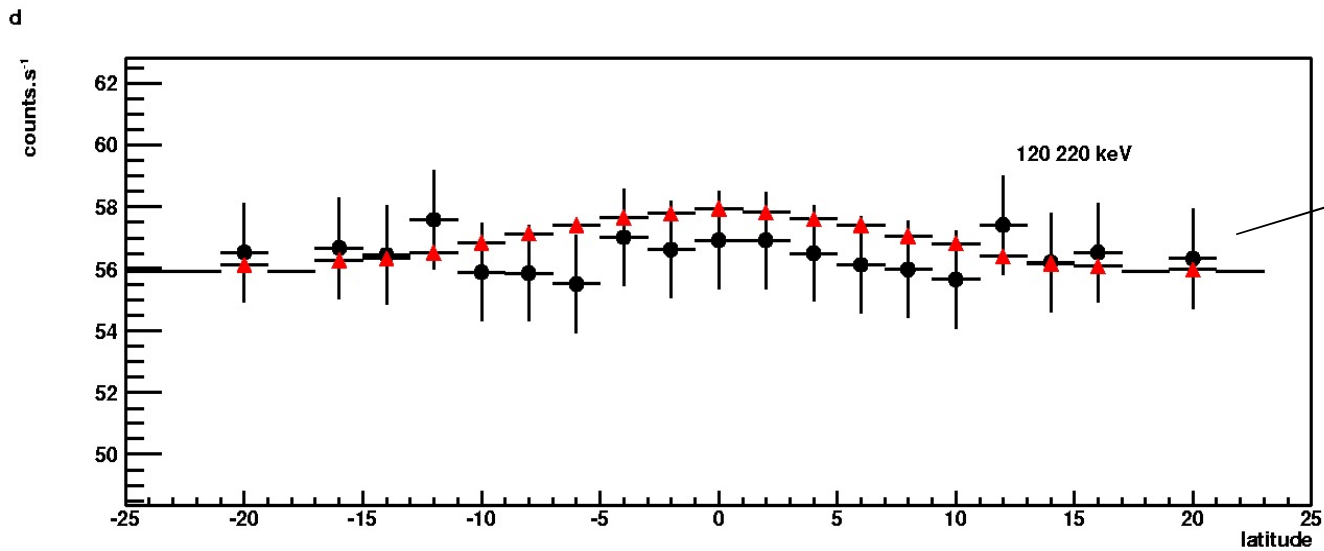
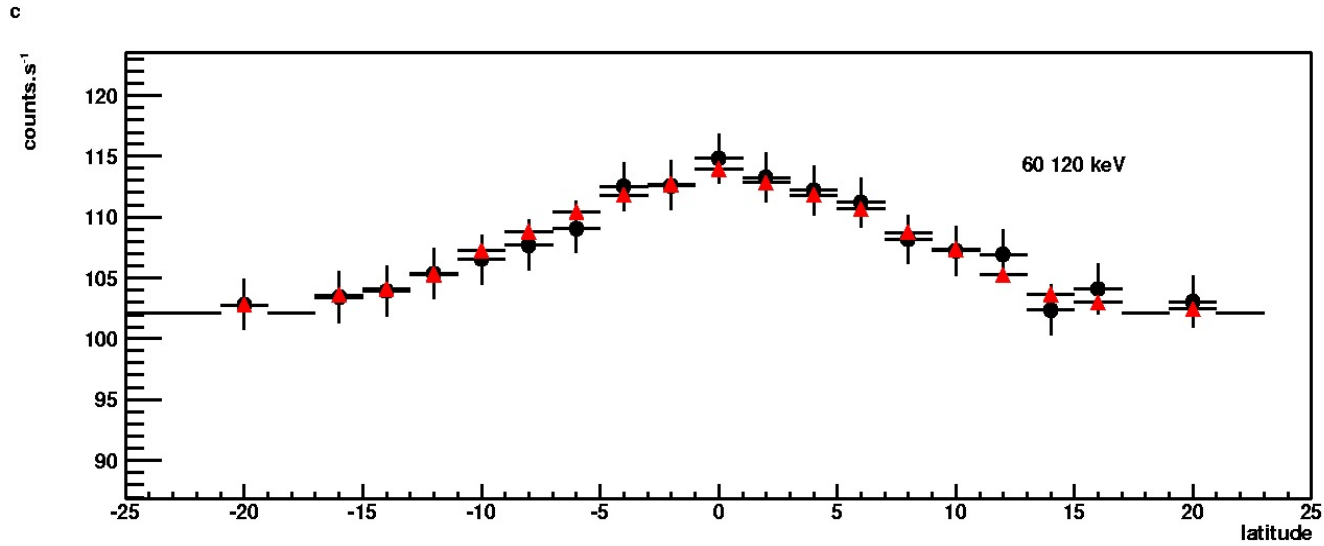
Sco-X1:  
large angle  
acceptance pb

b



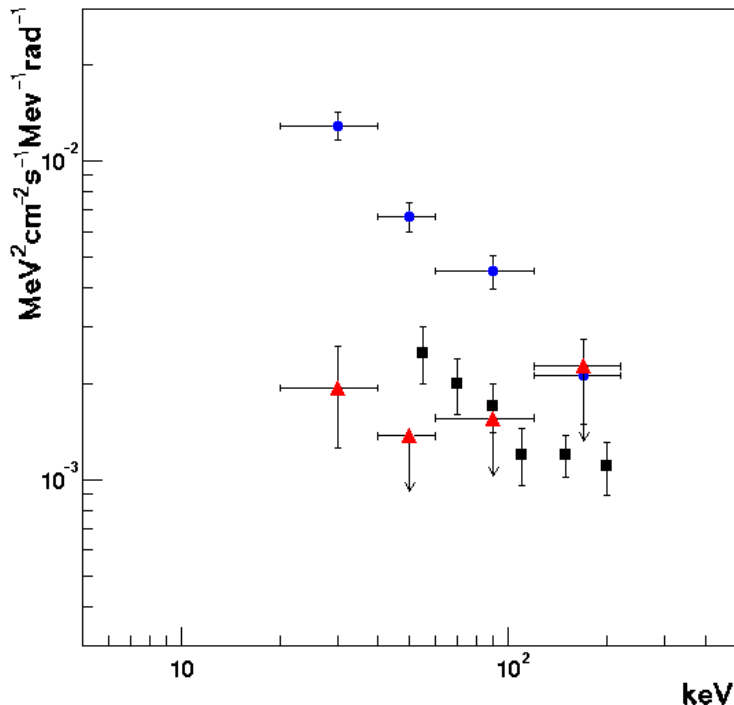
# Latitude profiles

$|\lambda| < 20^\circ$



## Remaining diffuse flux

20 – 40 keV	$8.6 \pm 2.9$ c/s	————→	$14 \pm 4.5\%$	of total Galactic emission
40 – 60 keV	$0.2 \pm 1.1$ c/s	————→	<19%	( $3\sigma$ ) of total Galactic emission
60 -120 keV	$0.7 \pm 1.3$ c/s	————→	<27%	( $3\sigma$ ) of total Galactic emission
120 – 220 keV	$-0.3 \pm 0.6$ c/s	————→	<52%	( $3\sigma$ ) of total Galactic emission



Reconstruct spectrum

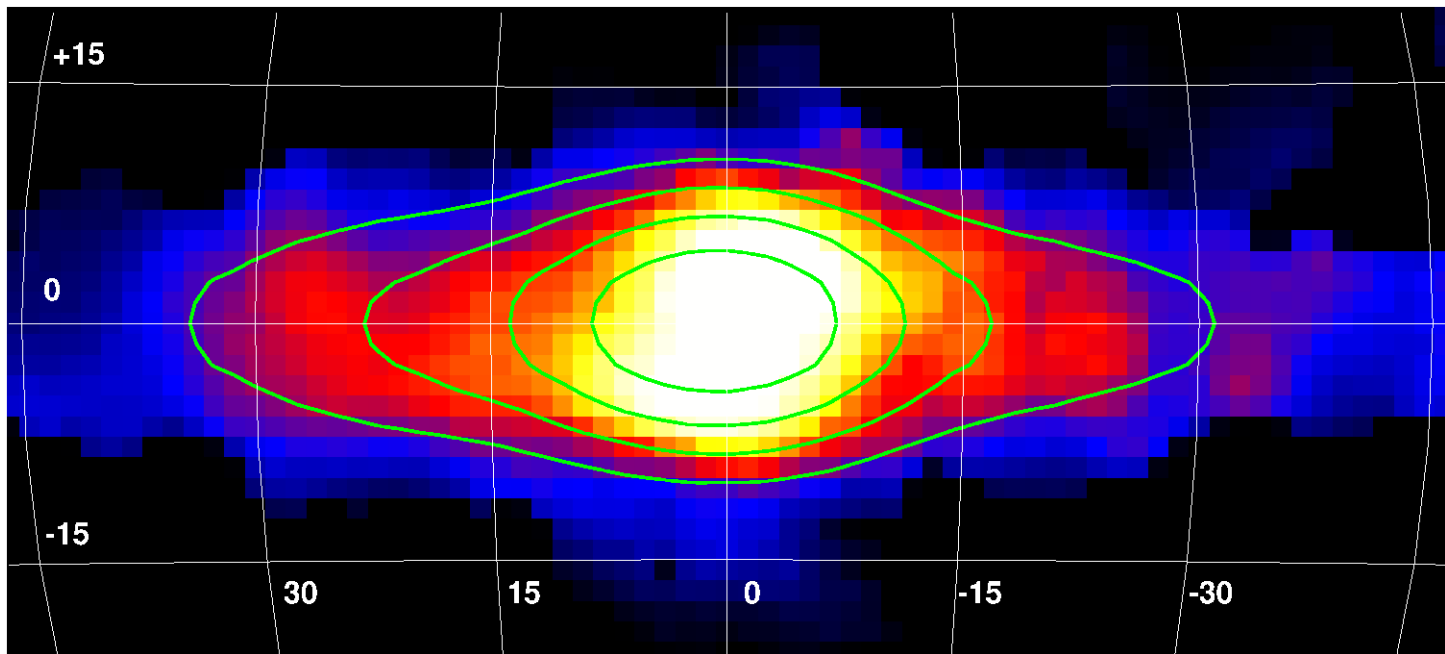
usual forward folding technique  
using arf and rmf

Difficulty with IBIS/Isgri:  
decrease of photoelectric efficiency  
> 100 keV

# Light bucket: making an image

Put residual flux at optical axis position and distribute it along your detector acceptance

Resulting structure has a spatial resolution of  $\sim 20^\circ$   
is influenced by dithering pattern





# Model fitting

Assume diffuse emission spatial distribution follows typical tracers

Typically CO & HI at high energies and IR at low energies (eg Bouchet et al)

Typical algorithm:

- Source detection (using one or several instruments)
- In each pointing
  - Estimate Bkg contribution using precalibrated model (high latitude data)
  - Fit source fluxes + diffuse component on bkg subtracted dataset

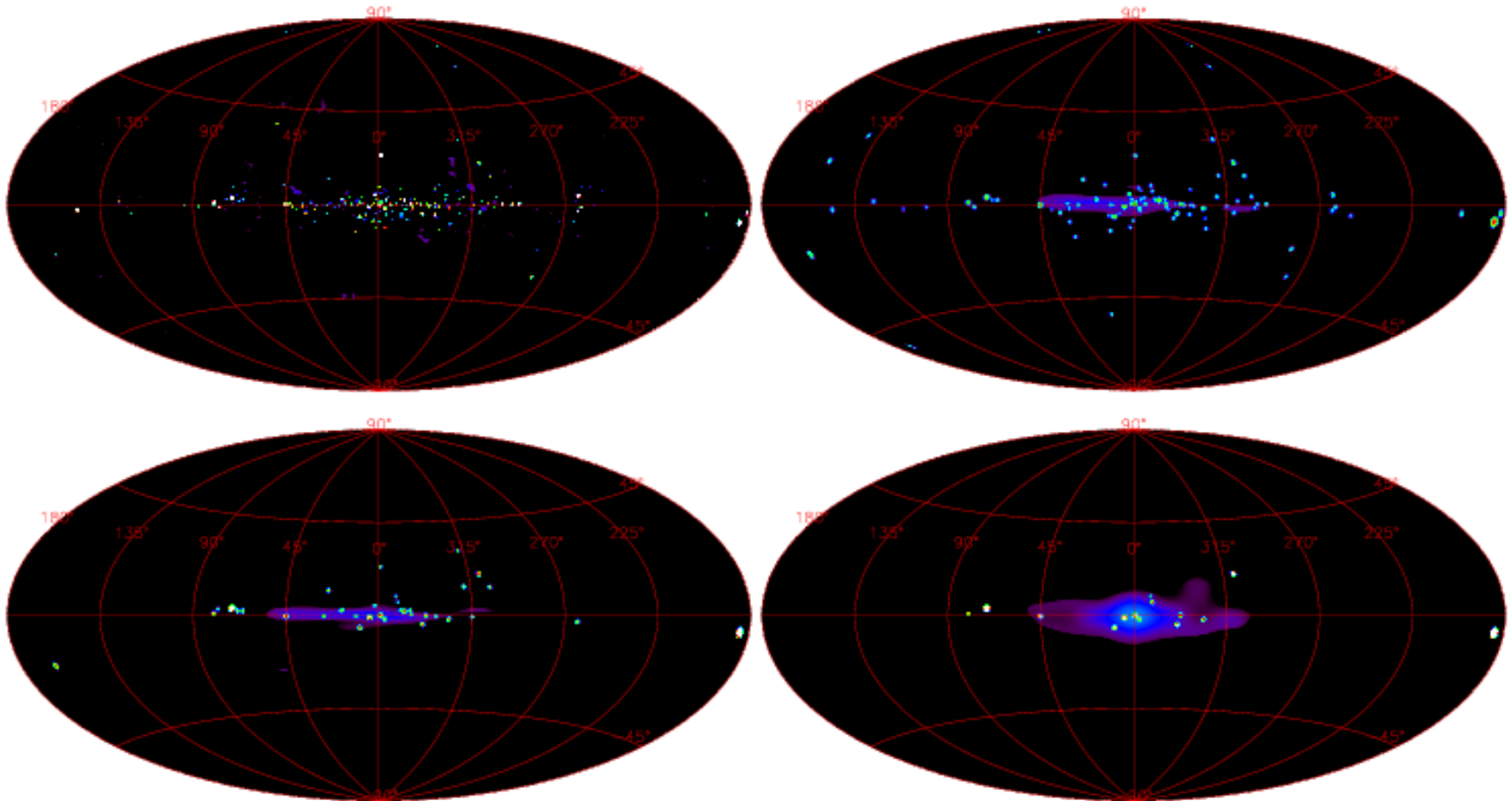
Difficulty of number of parameters:

- SPI has 19-16 active detectors : only 12 sources can vary on a scw basis
- Validity of the model used?

# Model fitting

Assume diffuse emission spatial distribution follows typical tracers

Typically CO & HI at high energies and IR at low energies (eg Bouchet et al)



# Model -independent maximum likelihood technique

Assume diffuse emission spatial distribution follows Galactic plane (somewhat reasonable assumption)

- e.g.  $16 \times 2^\circ$  bins in Bouchet et al (2008)

Typical algorithm:

- Source detection (using one or several instruments)
- In each pointing
  - Estimate Bkg contribution using precalibrated model (high latitude data)
  - Fit source fluxes + template diffuse component on bkg subtracted dataset
- Using fitted sources fluxes
  - Determine diffuse fluxes in each spatial bins

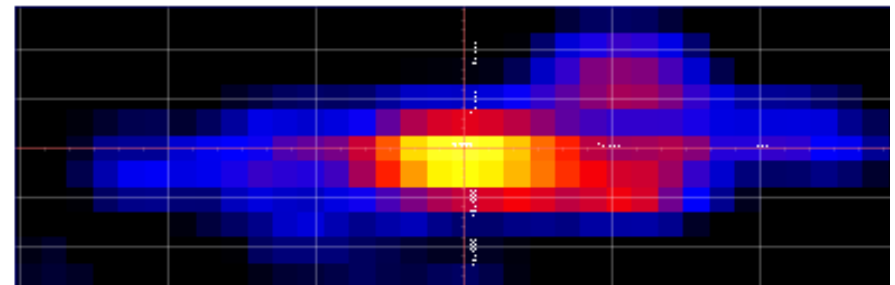
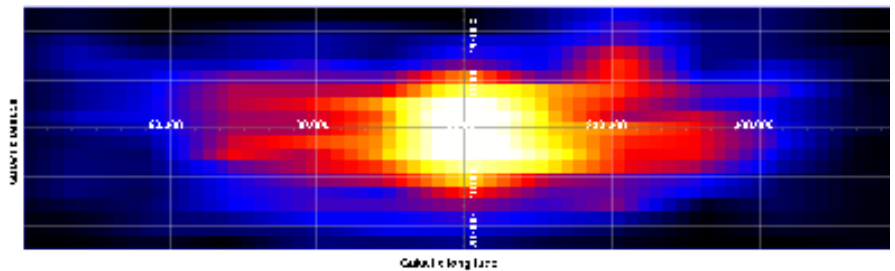
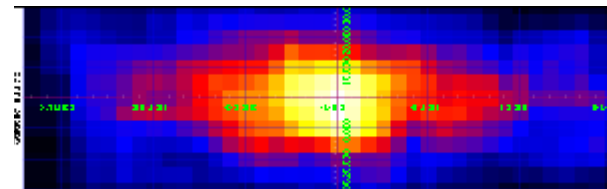
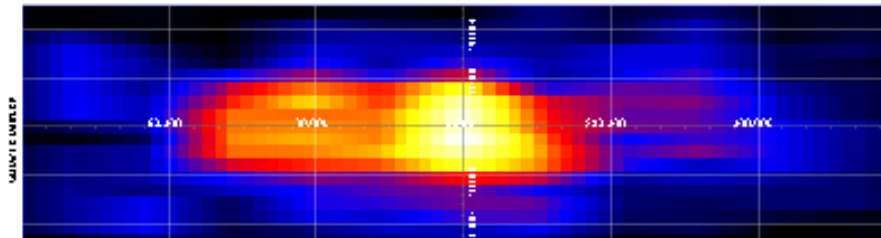
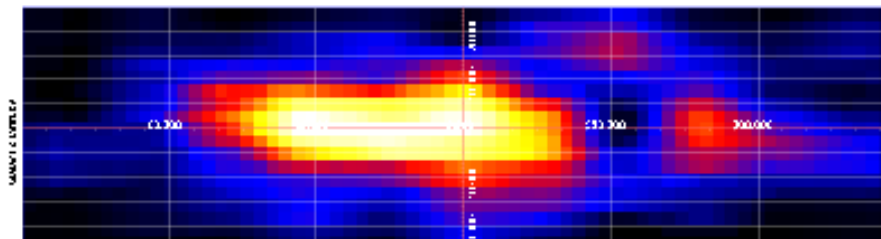
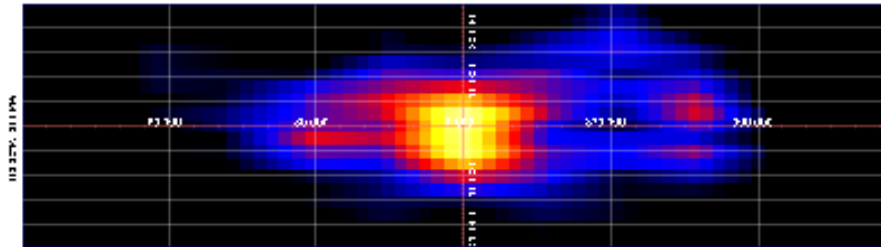
Difficulty of number of parameters:

- SPI has 19-16 active detectors : only few sources can vary on a scw basis

# Model - independent maximum likelihood technique

Assume diffuse emission spatial distribution follows Galactic plane (somewhat reasonable assumption)

- e.g.  $16 \times 2^\circ$  bins in Bouchet et al (2008)



# Summary & future prospects

## **Main difficulties in this energy range:**

### **Point source contamination:**

Need sensitive high resolution instrument

### **High background environnement**

Need precise internal bkg model (including CR induced bkg and also internal activation)

### **Impossible to make direct images of very extended structures:**

Light bucket: poor angular resolution

Model fitting : large number of parameters

up to 120 sources per pointing (a significant number of which is varying)

## **To give a more precise determination of the level of diffuse emission:**

- Need to use all instruments on board Integral:
  - Simultaneous independent measurements (sources & diffuse)
- Improve bkg determination
- logN-logS studies to evaluate undetected sources contribution

## **Volunteers?**