IBIS data analysis

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Contributions

The IBIS/ISGRI scientific data analysis s/w defined and developed to be implemented in the ISDC system as Instrument Specific SoftWare (ISSW) is the result of the work of a large team in the IBIS institutes and in ISDC (1999-2012). Main contributions were provide by:

ISSW Definition and Development:
S. Chazalmartin, P. David, A. Goldwurm, A. Gros, P. Laurent, A. Sauvageon (SAp - Saclay)
L. Lerusse, N. Produit, (ISDC – Versoix)

Instrument responses, bkg and calibration files, algorithms:
F. Lebrun, P. Laurent, R. Terrier, I. Caballero, S. Soldi, J. Zuritah (SAp – Saclay)

Tests and control of performances:
G. Belanger, M. Cadolle Bel, M. Falanga, M. Forot, P. Goldoni, S. Kuznetsov, M. Renaud, J. Rodriguez (SAp – Saclay)
L. Foschini (IASF – Bologna)
Del Santo, L. Natalucci (IASF – Roma)
Others … at ISDC – Versoix

References

Coded mask imaging:

Fenimore & Cannon,1979 & 1981, App. Opt.
Gottesman & Fenimore, 1989, App. Opt.

Data analysis for the SIGMA/GRANAT experiment:

Goldwurm, 1995, Exp. Astr.
Bouchet et al., 2001, Ap.J.

IBIS data analysis concepts:

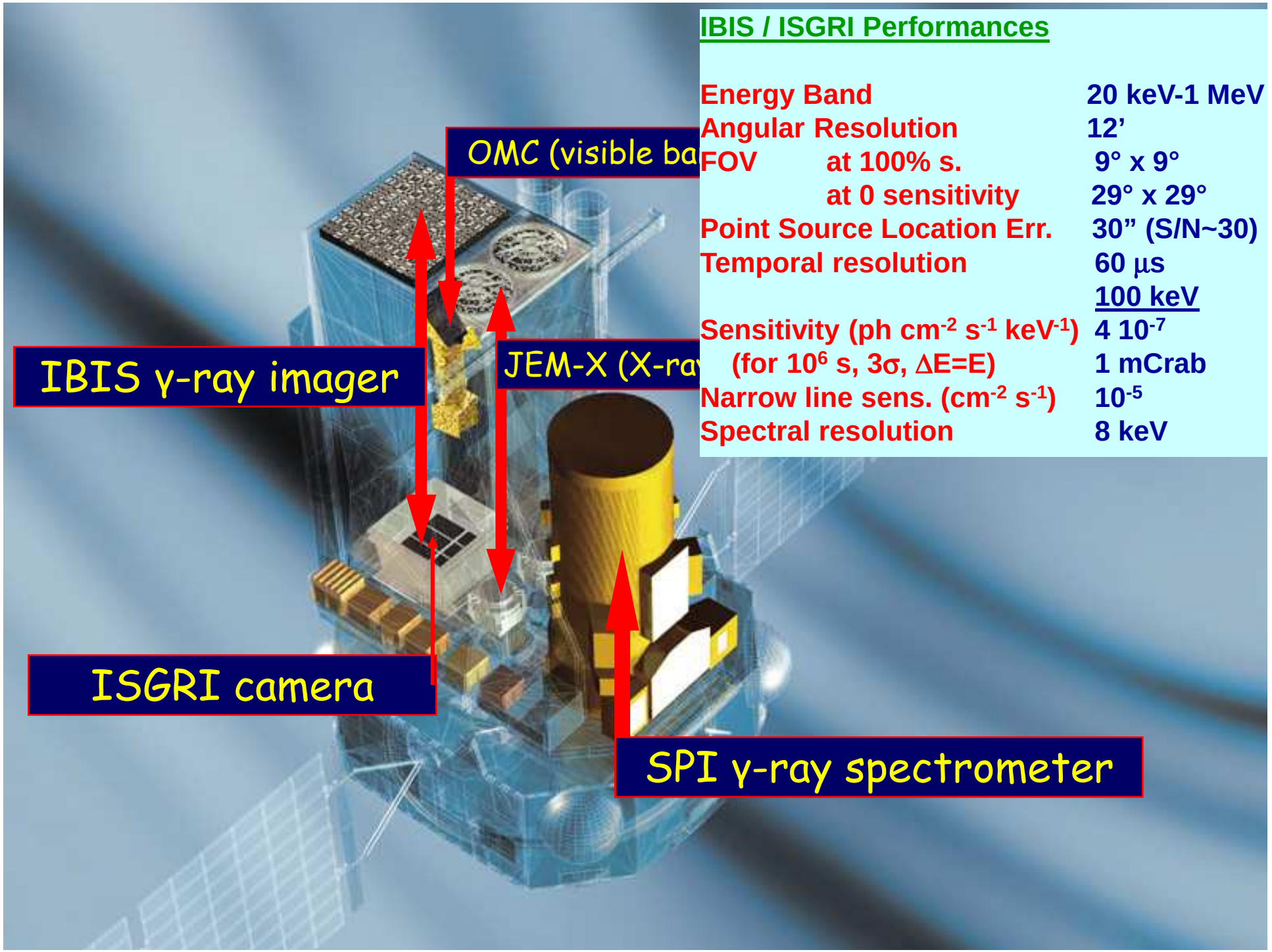
Goldwurm et al., 2001, ESA - SP
Goldwurm et al., 2003, A&A, 411
Gros et al., 2003, A&A, 411

IBIS/ISGRI in-flight calibrations, responses, performances:

Lebrun et al. 2003 and Terrier et al., 2003, A&A, 411
Sauvageon et al., 2003, IBIS Report
Natalucci et al., 2004, IBIS Report

IBIS data analysis manual (documentation at ISDC site):

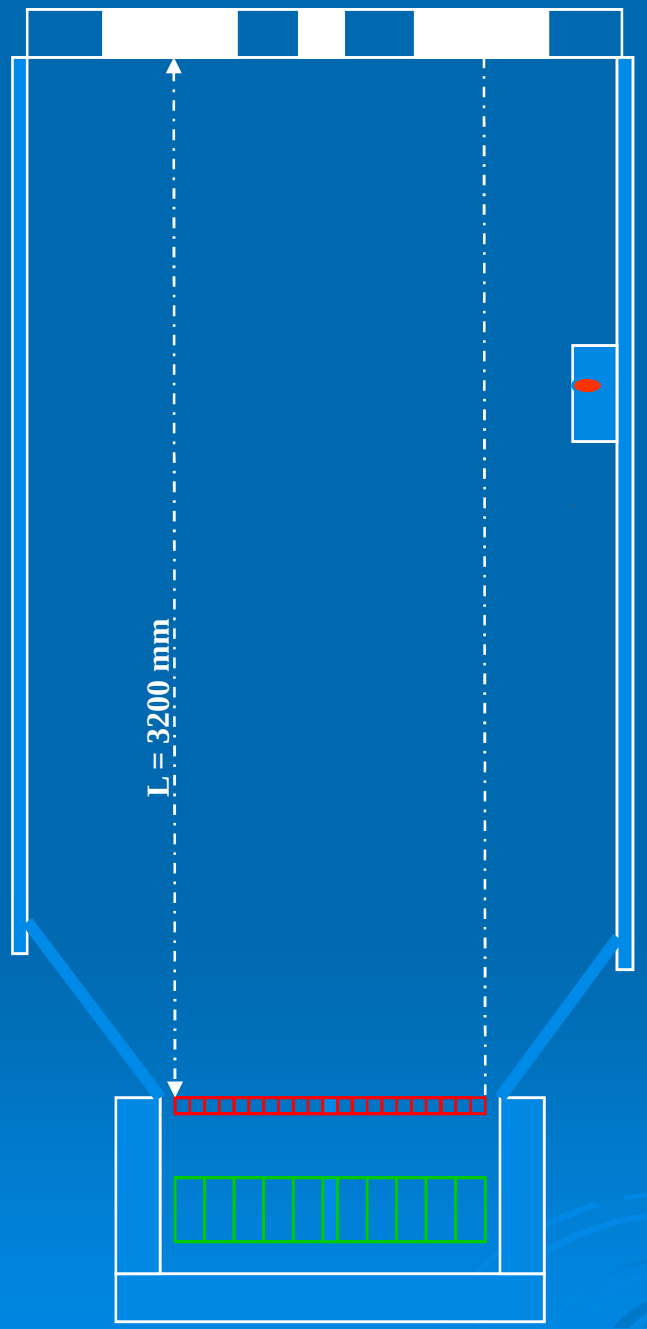
Chernyakova, 2004, IBIS Data Analysis Manual
Goldwurm Science Validation Report



IBIS / ISGRI Performances

Energy Band	20 keV-1 MeV
Angular Resolution	12’
FOV at 100% s.	9° x 9°
FOV at 0 sensitivity	29° x 29°
Point Source Location Err.	30” (S/N~30)
Temporal resolution	60 μs
	100 keV
Sensitivity (ph cm^{-2} s^{-1} keV^{-1})	$4\ 10^{-7}$
(for 10^6 s, 3σ, ΔE=E)	1 mCrab
Narrow line sens. (cm^{-2} s^{-1})	10^{-5}
Spectral resolution	8 keV

The Coded Mask IBIS Telescope



Mask :
53 x 53 MURA basic pattern,
95 x 95 W elem. of size 11.2 x 11.2 mm^2
at a distance L = 3.2 m from the detector

Positional Detectors :
ISGRI : 128 x 128 pix
PICsIT : 64 x 64 pix bars
Some dead-zones, off pixels

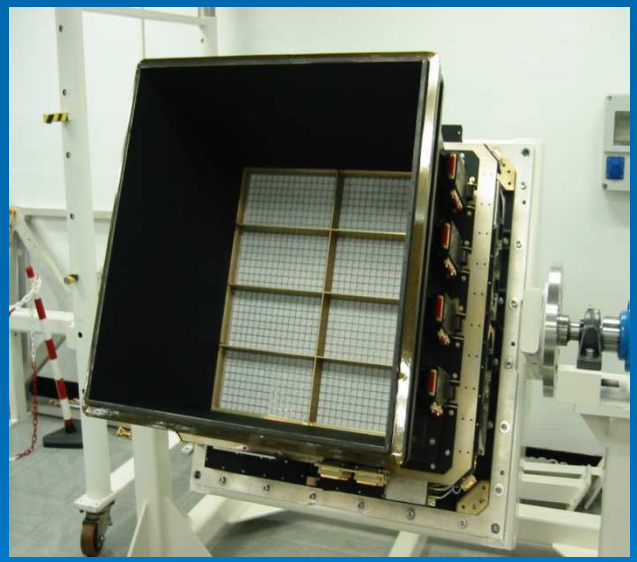
Shielding system, Veto and CU :
Passive (tube, hopper)
Veto Unit : 16 BGO mod
Calibration Unit : ^{22}Na Source

The IBIS data structure

ISGRI : The Soft Gamma-Ray Imager

New-generation gamma-camera of Cadmium Telluride (CdTe), semiconductor with high Z (48-52) working at room temperature.

128 x 128 = 16384 pixels (4 x 4 mm^2, 2 mm thick) in 8 modules
Energy range : 20 - 1000 keV
Spatial resolution : 4.6 mm (separation of pixel centers)



ISGRI Data in the Telemetry:

- Single-Event List with
  Y Z Pha RT t (S1)
- Calibration single event (S2)
- Contexts of the Instrument
  (pixels off, thresholds, gains) (CTX)
- House-keepings (HK)
  (ratemeters, temperatures,
  voltage, pixels status, etc.)

PiCsIT: Pixelated CsI Telescope

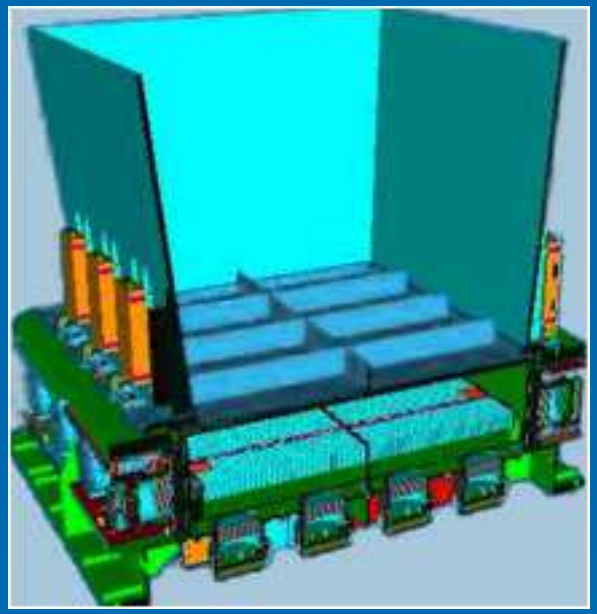
gamma-camera made of CsI read by photodiods:

64 x 64 = 4096 pixels (8 x 8 mm^2, 3 cm thick) in 8 modules
Energy range : 200 - 10000 keV
Spatial resolution : 9.2 mm (separation of pixel centers)

PiCsIT Data in the Telemetry:

- Single-Event List with
  Y Z Pha t
-Histograms (Imaging, Spectral-timing)
-Contexts of the Instrument
  (pixels off, thresholds, gains) (CTX)
- House-keepings (HK)
  (ratemeters, temperatures,
  voltage, pixels status, etc.)

Compton events : ISGRI + PiCsIT



Compton Data in the Telemetry:

- Single-Event List with :

CAL_FLAG, TIME_TAG,
ISGRI_RT, ISGRI_PHA, ISGRI_Y, ISGRI_Z,
PICSIT_PHA, PICSIT_Y, PICSIT_Z,
OB_TIME.
-Contexts of the Instrument and house-keepings given independently by ISGRI and PiCsIT

See file : compton_events.txt !

(real Compton data file of GRB041219A observation, as available at ISDC)

Compton events : ISGRI + PiCsIT

compton_events.txt - Bloc-notes

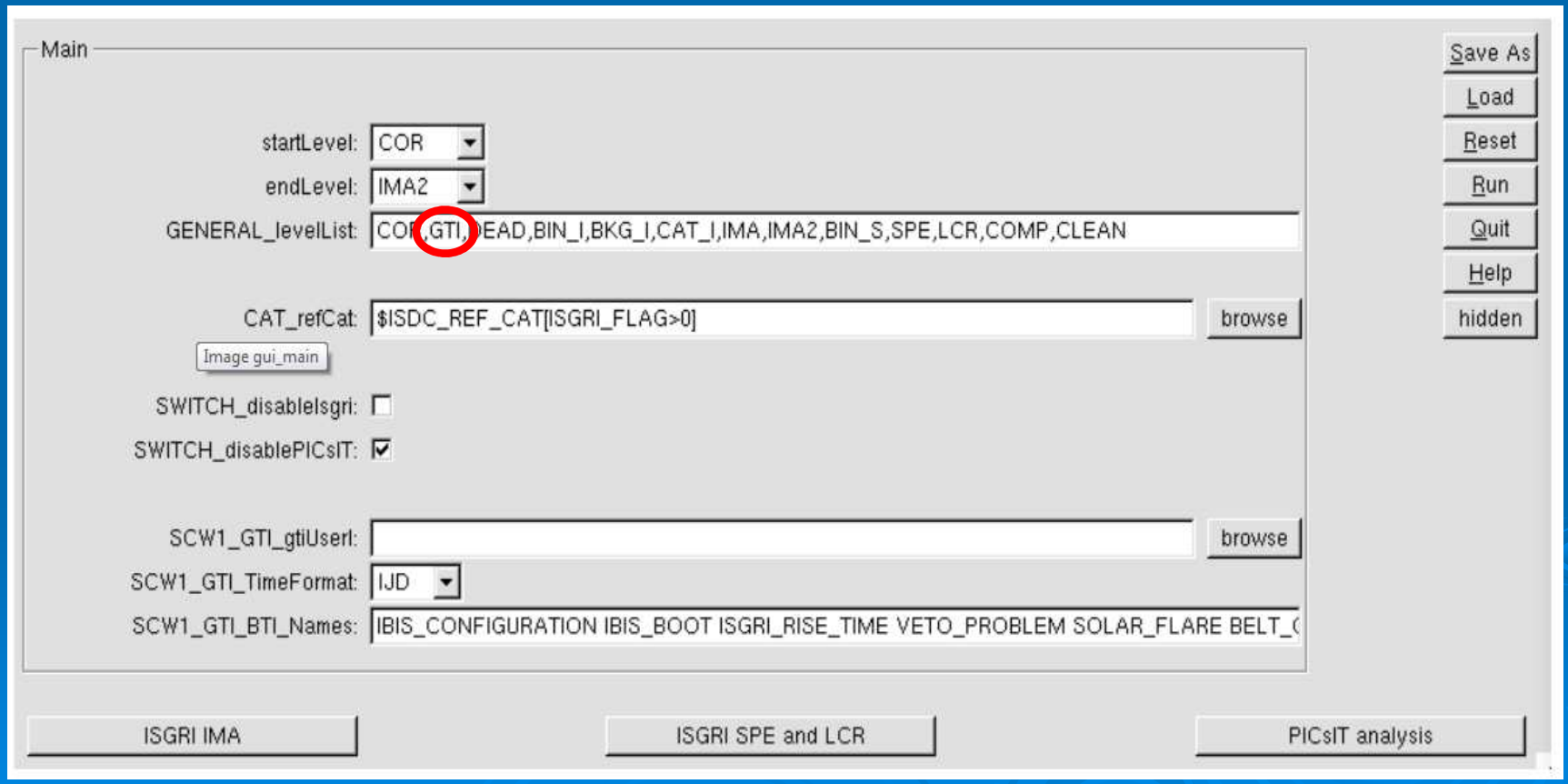
Fichier Edition Format Affichage ?

CAL_FLAG	TIME_TAG	DUMMY_COUNTER	RISE_TIME	ISGRI_PHA	ISGRI_Y	ISGRI_Z	PICSIT_PHA	PICSIT_Y	PICSIT_Z					
OB_TIME	ISGRI_PI	ISGRI_ENERGY	PICSIT_ENERGY	SELECT_FLAG		TIME								
1B	1B	1B	1B	1B	1B	1B	1B	1B	1B					
4I	1B	1E	1E	1B		1D								
		keV	keV			d								
1	244	0	56	4	15	109	7	38	50	0	16748	10392	48382	104
2.246640E+01	1.987502E+02	0	1.814057260909E+03											
1	101	1	30	32	4	48	9	18	28	0	16748	10393	6462	52
1.669331E+02	2.375398E+02	0	1.814057261170E+03											
1	219	1	103	23	12	31	23	30	42	0	16748	10393	30398	181
0.000000E+00	6.525006E+02	0	1.814057261434E+03											
1	254	0	73	7	31	96	10	34	18	0	16748	10393	32638	113
4.183307E+01	2.784915E+02	0	1.814057261459E+03											
1	174	0	32	27	72	97	29	51	49	0	16748	10393	43902	54
1.368664E+02	8.198958E+02	0	1.814057261583E+03											
1	186	0	22	9	61	111	13	61	19	0	16748	10393	44670	42
5.293307E+01	3.640682E+02	0	1.814057261591E+03											
1	98	0	93	7	14	21	9	14	2	0	16748	10393	55422	132
9.549973E+01	2.467573E+02	0	1.814057261710E+03											
1	18	0	54	147	62	67	7	4	34	0	16748	10394	1150	79
9.467331E+02	1.965084E+02	0	1.814057261834E+03											
1	159	0	20	4	110	110	15	19	31	0	16748	10394	10174	38
2.383307E+01	4.106757E+02	0	1.814057261934E+03											
1	190	0	69	24	36	73	36	9	25	0	16748	10394	12158	111
2.141997E+02	1.023897E+03	0	1.814057261956E+03											
1	178	1	36	64	33	29	79	37	4	0	16748	10394	44158	48
3.470664E+02	2.237954E+03	0	1.814057262309E+03											
1	253	0	18	9	24	114	6	44	14	0	16748	10394	48958	33
4.969973E+01	1.704183E+02	0	1.814057262362E+03											
1	6	0	68	59	33	78	73	20	30	0	16748	10394	49534	112
4.949664E+02	2.055700E+03	0	1.814057262369E+03											
1	203	0	49	17	76	124	7	49	36	0	16748	10394	62142	79
1.122331E+02	1.884747E+02	0	1.814057262508E+03											
1	57	0	62	34	122	24	75	55	4	0	16748	10395	3646	99
2.706997E+02	2.111536E+03	0	1.814057262585E+03											
1	242	0	18	46	108	26	9	43	33	0	16748	10395	15486	31
2.364331E+02	2.455657E+02	0	1.814057262716E+03											
1	245	1	84	7	105	78	29	58	50	0	16748	10395	32062	136
0.000000E+00	8.277819E+02	0	1.814057262899E+03											
1	108	0	58	38	51	93	10	15	32	0	16748	10395	39678	80
2.411664E+02	2.734862E+02	0	1.814057262983E+03											
1	112	1	72	16	109	9	11	47	7	0	16748	10395	56218	122

The IBIS data analysis

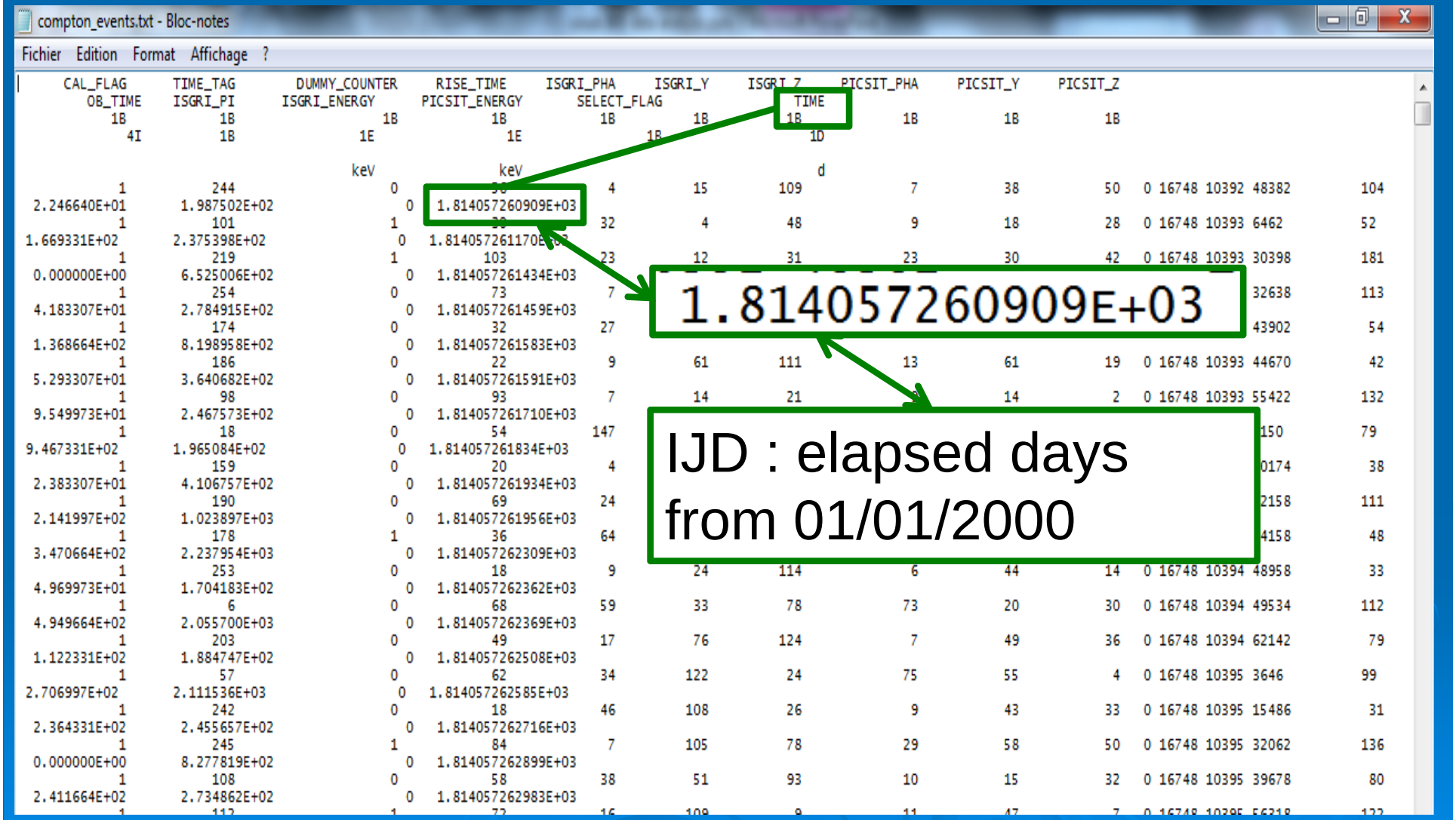
Standard analysis Web Interface at ISDC

⇒ launching ibis_science_analysis (tomorrow !) …

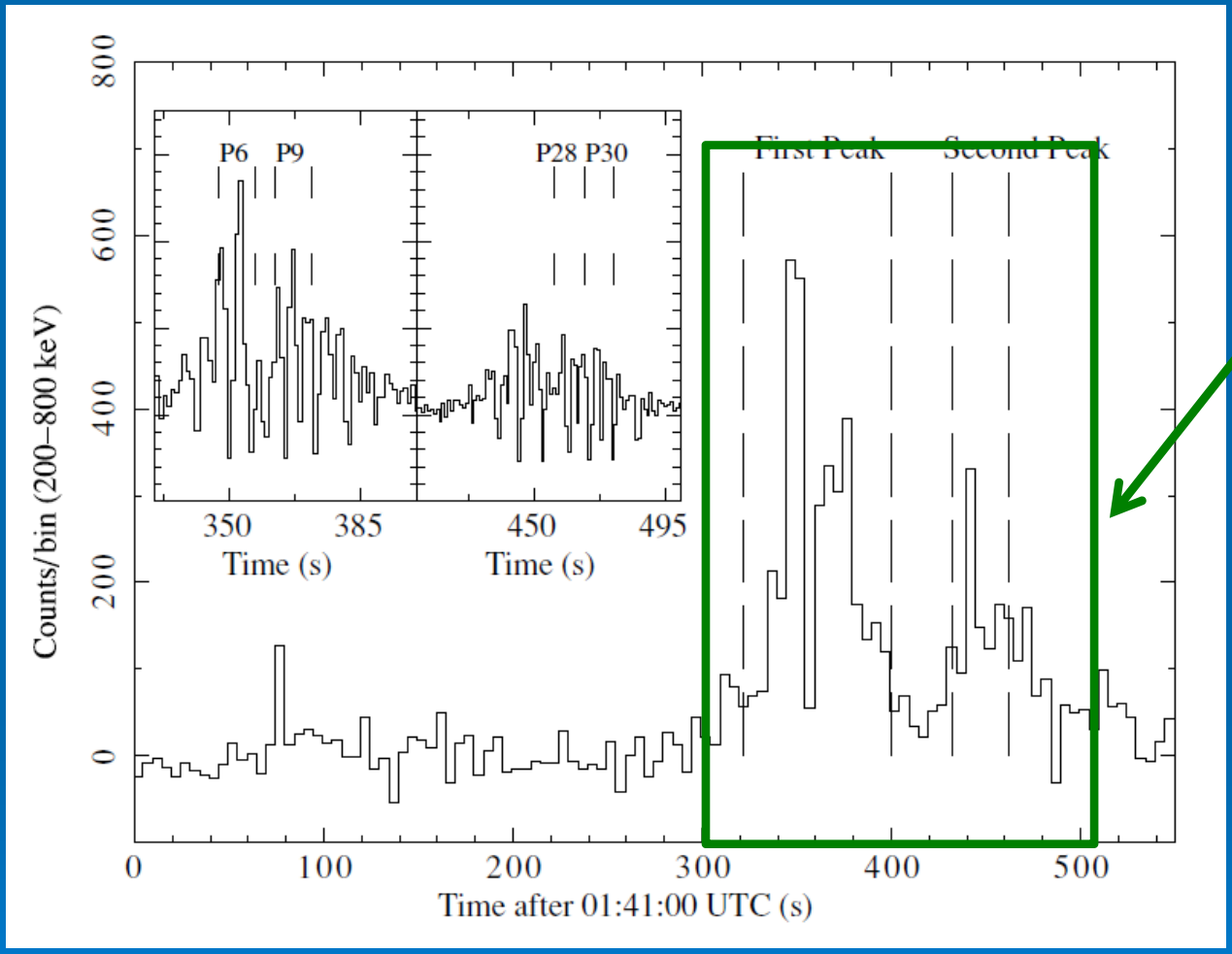


IBIS data analysis:
1. Selection of Good Time Intervals (GTI)

Compton events : ISGRI + PiCsIT



GTI of GRB 041219A



5 s bins

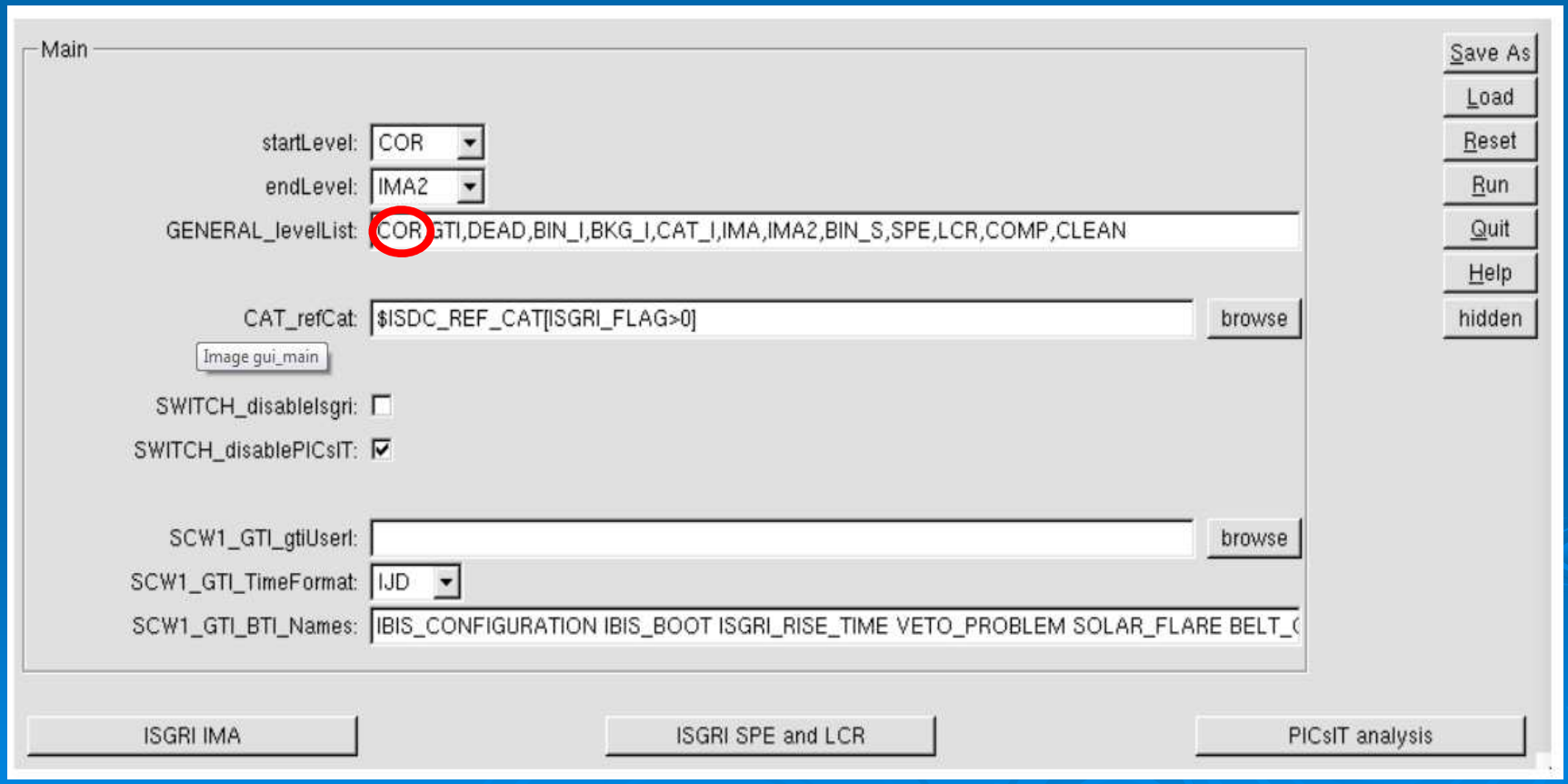
GTI : Find the burst !

See file : compton_events_sel.txt !

(events after IJD = 1814,0735 days)

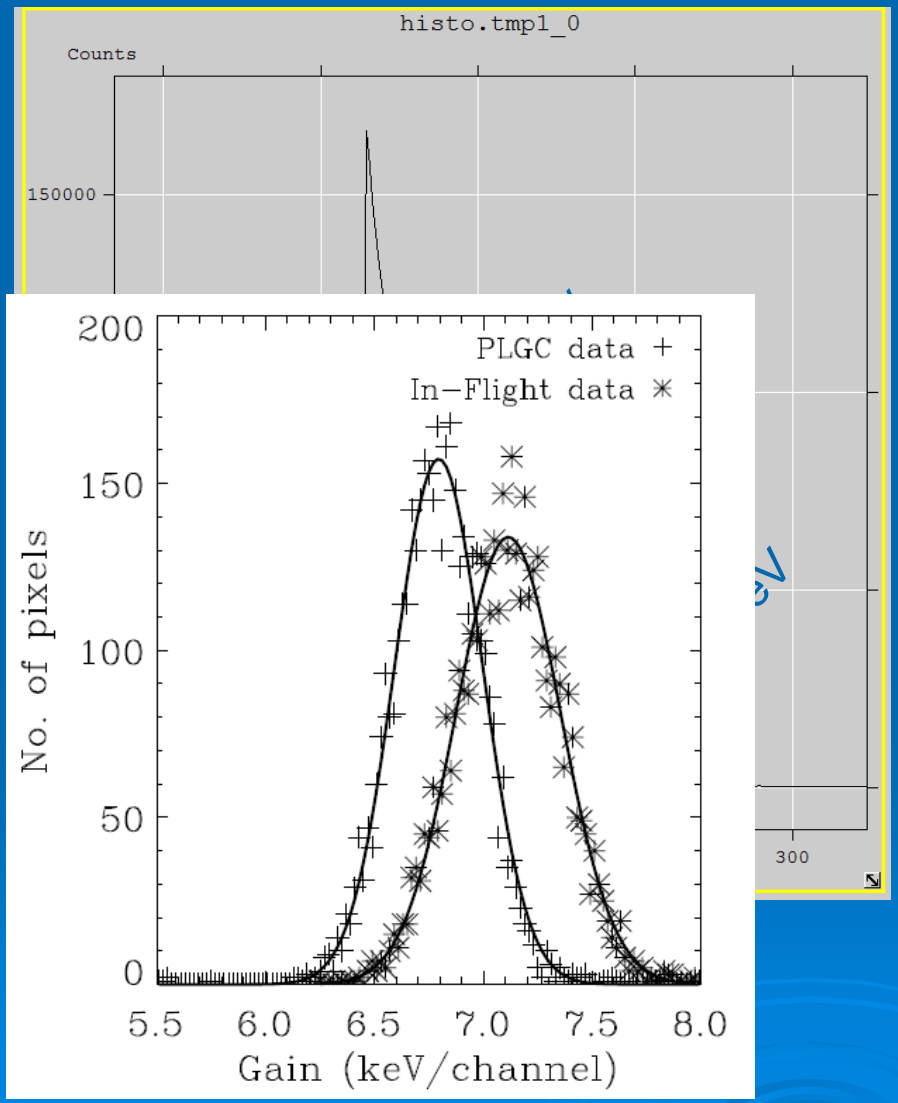
Standard analysis Web Interface at ISDC

⇒ launching ibis_science_analysis …



IBIS data analysis:
2. Energy correction (COR)

General case : PiCsIT



PHA proportional to Energy deposit
Integral On-Ground Calibration:

^{22}Na
two lines : 511 and 1275 keV

see run_4732_S40.txt file !

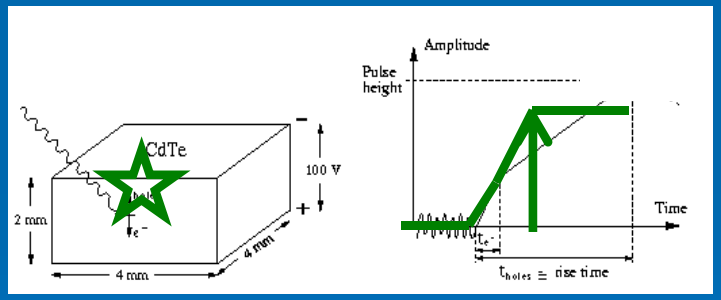
511 keV : channel 76.26
1275 keV : channel 190.06

Gain = (1275.-511.)/(190.06-76.26)
Gain = 6.714 keV/channel

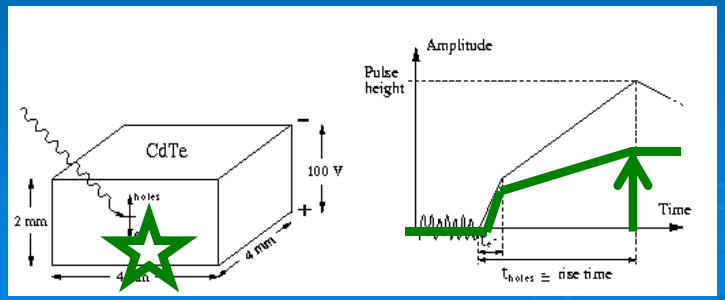
Offset = 511 – 6.714x76.26 = -1 keV

ISGRI specific effects: Charge Loss

Charge-Loss	Holes take more time to reach the electrode and a larger charge loss occurs the deeper is the interaction
Rise-Time	The energy loss is related to the pulse rise time (RT) which is measured and transmitted to ground
Correction	Rise-time can be used to correct the pulse heights (Pha) and compute the deposited energy

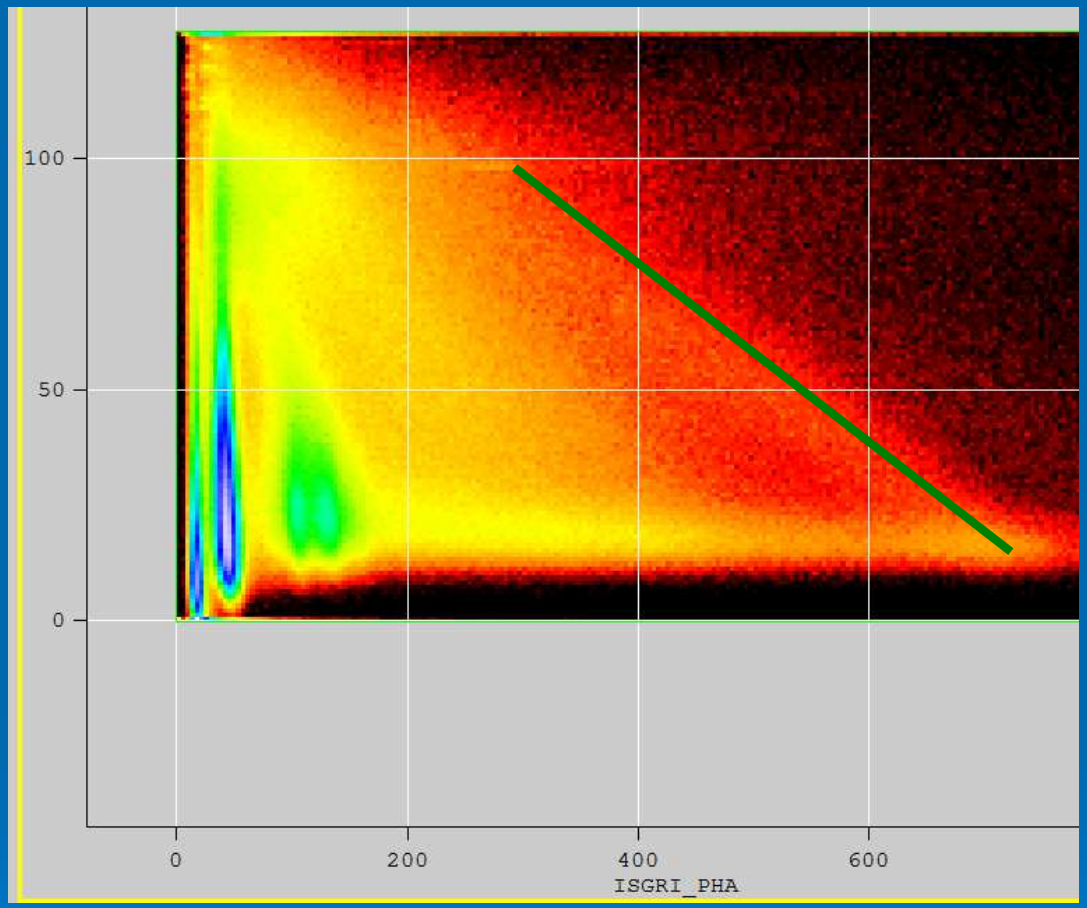


Short risetime ; no loss ⇒ full amplitude



Long risetime ; loss ⇒ partial amplitude

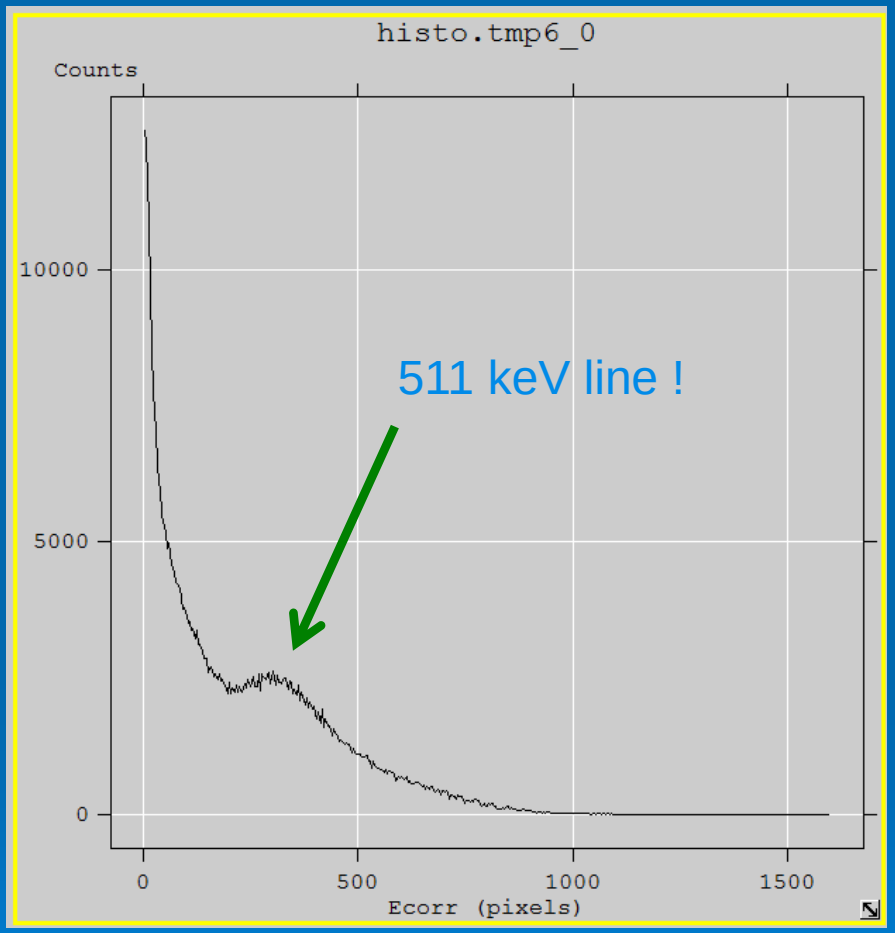
Charge Loss in S2 data



See isgri_raw_events.txt file !!

ISGRI bi-parametric diagram showing the variation of pulse height with rise-time due charge-loss effect for in-flight data S2 (CU tagged)

Charge Loss in S2 data

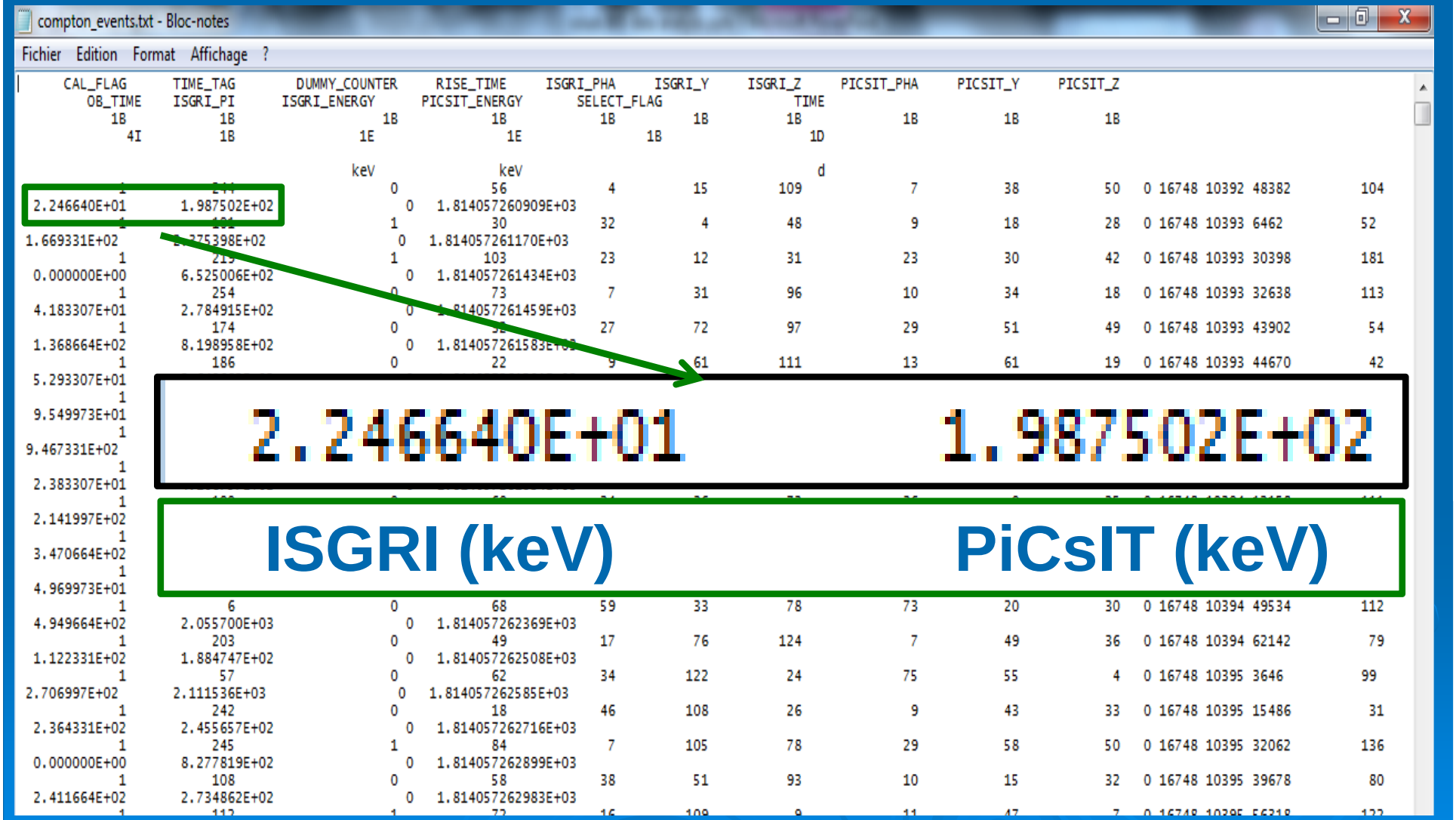


Events with 300<Amp<710

Amp : 709 Corr : 1.0 RT : 17
Amp : 332 Corr : 0.468 RT : 90

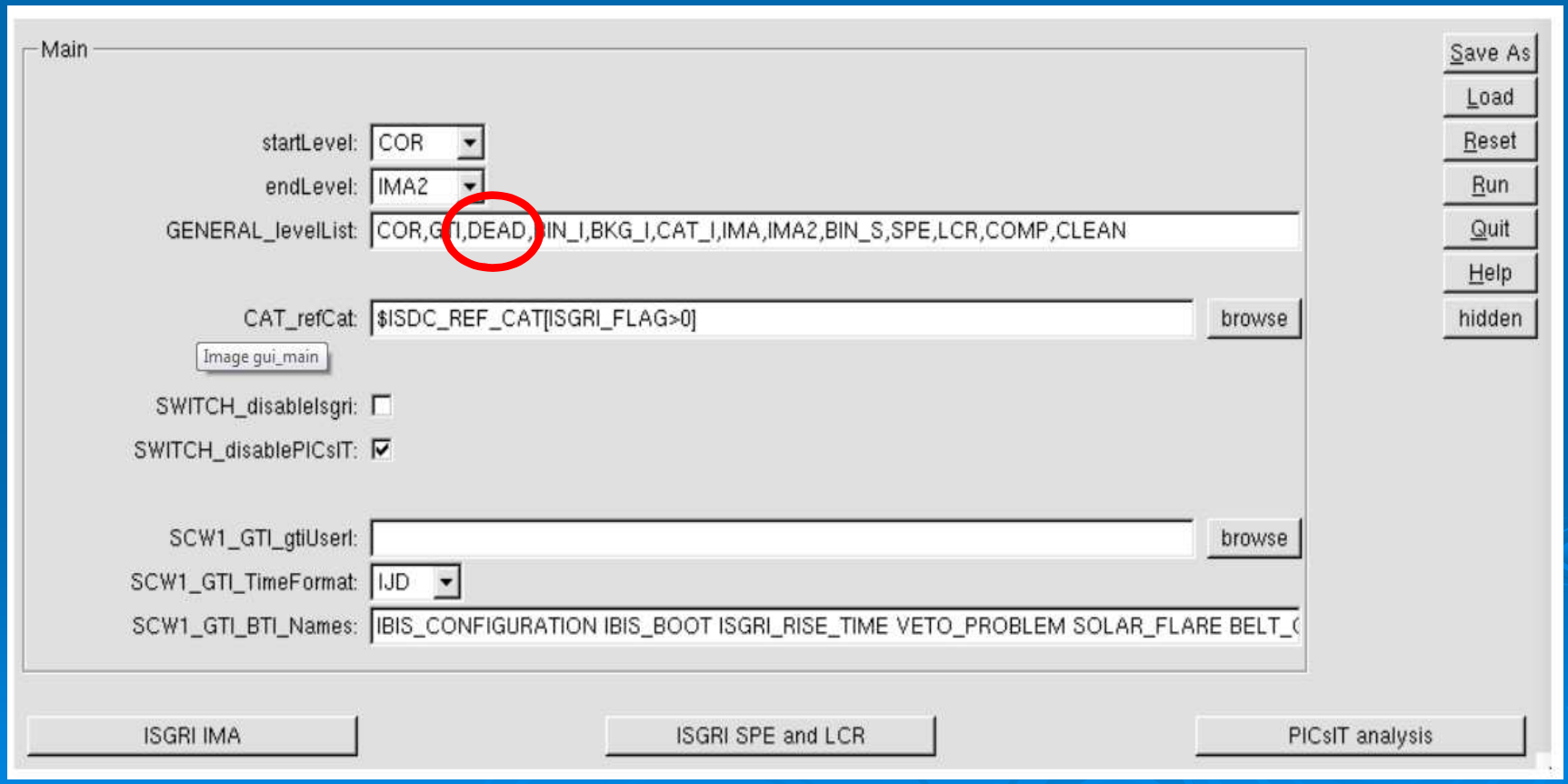
Amp_corr = Corr*Amp
with
Corr = a*RT + b
a = (1-0.468)/(17-90) = -0.00729
b = 1 + 0.00729x17 = 1.12393

Compton events : GTI + 250 keV < E < 800 keV



Standard analysis Web Interface at ISDC

⇒ launching ibis_science_analysis …



IBIS data analysis:
3. Dead-time correction (DEAD)

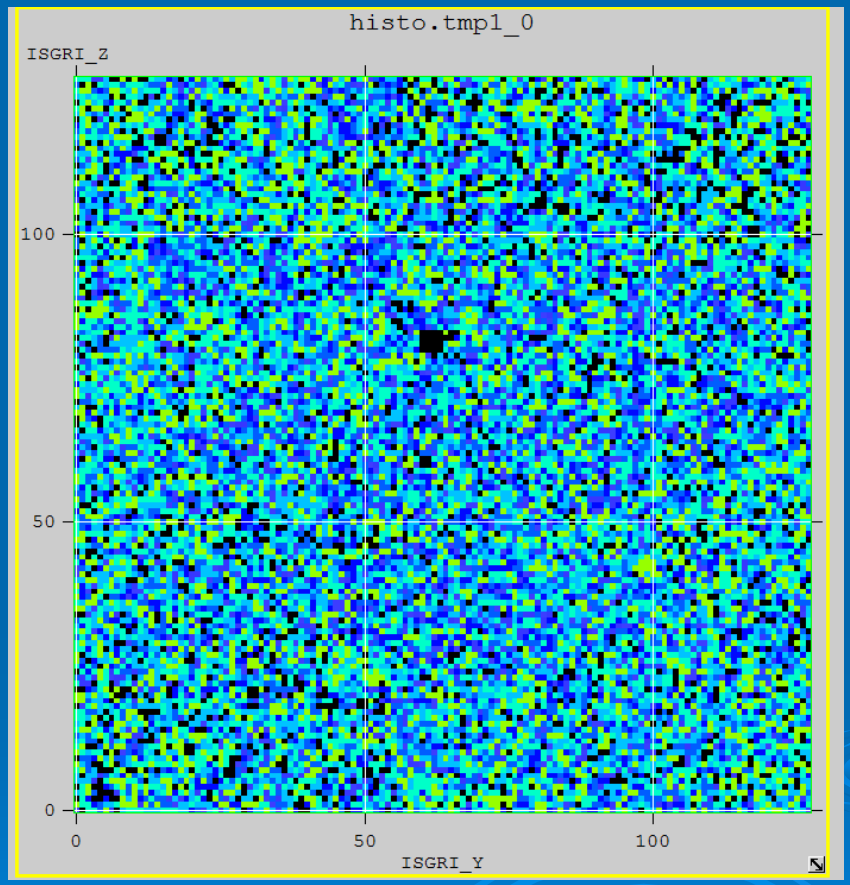
The ISGRI Noisy pixels

The ISGRI CdTe pixels are not all stable.

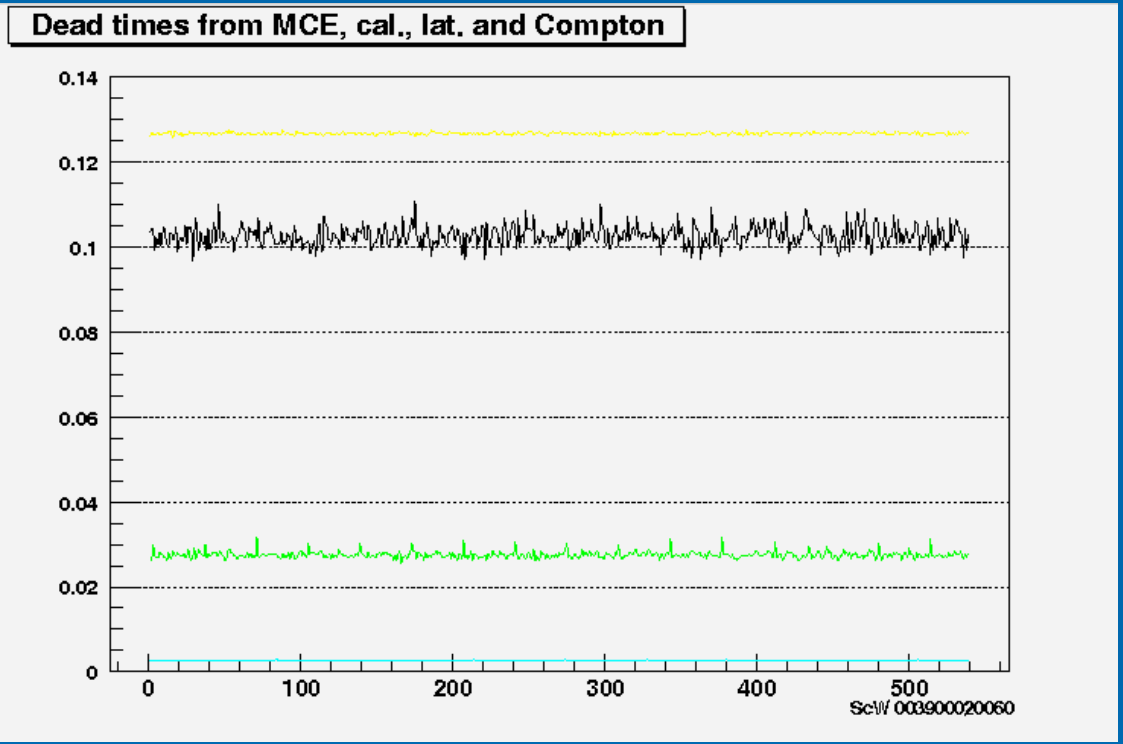
In spite of strong selection during manufacturing about 5% of them suffer from intrinsic noise.

An on-board s/w detects and switches OFF noisy pixels, then periodically resets them ON.

The very bad ones are set off in the Context (worked out each revolution)



Computation of ISGRI Deadtimes



ISGRI deadtimes due to different effects

ISGRI deadtime

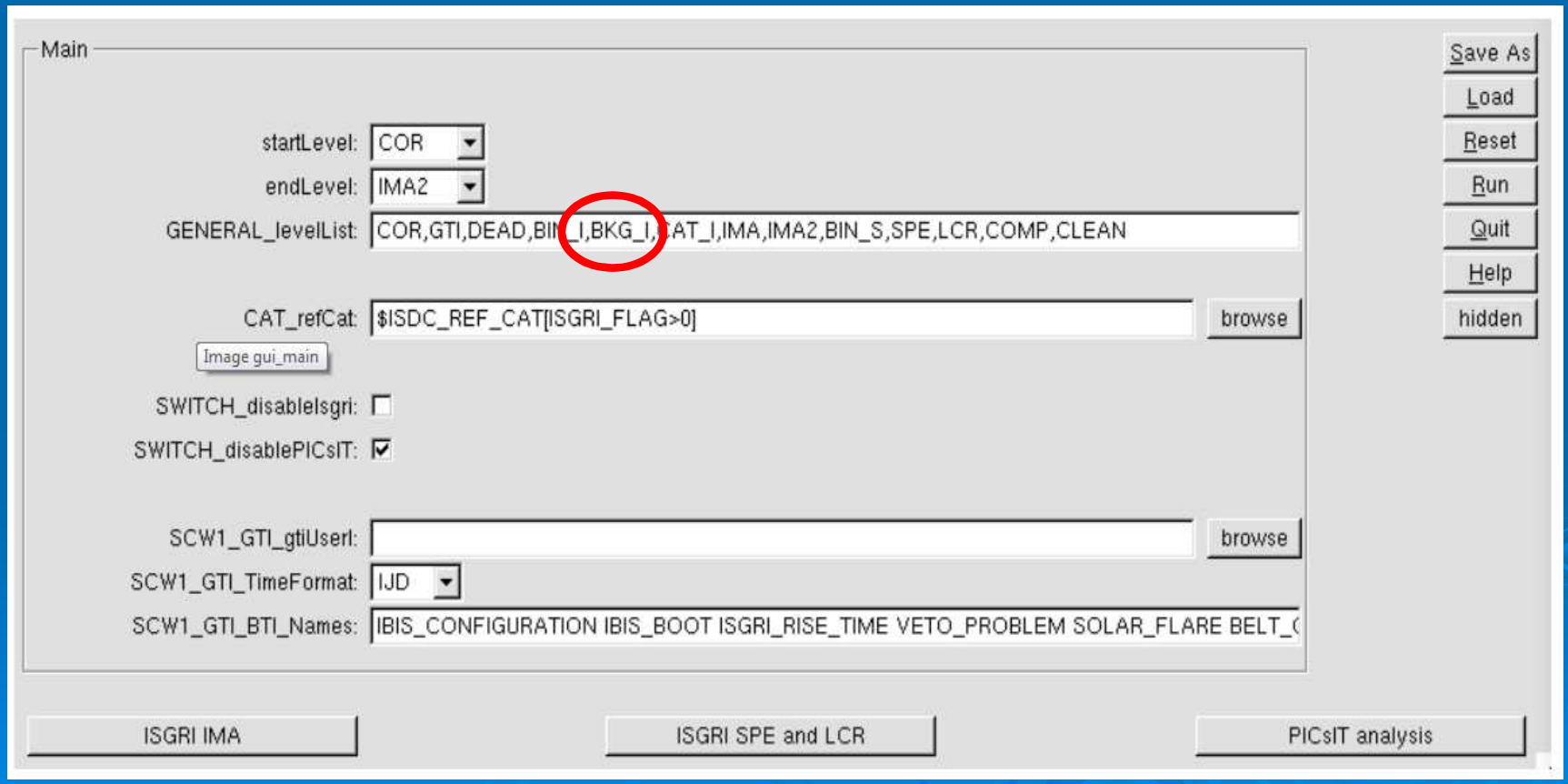
Random coincience CU

Random-coincidence Veto DT

Random-coincidence Compton DT

Standard analysis Web Interface at ISDC

⇒ launching ibis_science_analysis …

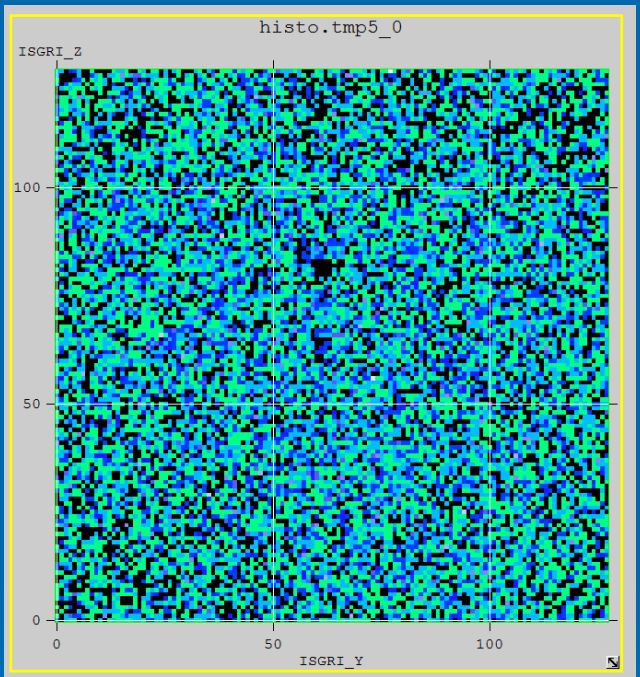


IBIS data analysis:

4. Background and uniformity correction (BKG_I)

Shadow Build – Uniformity Background Correction

Detector map

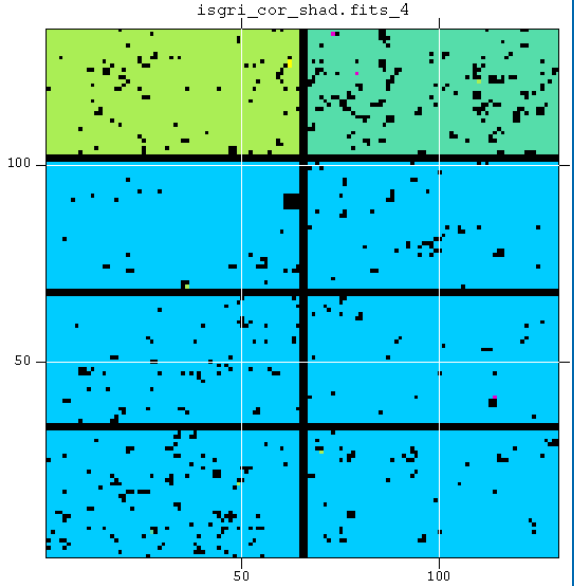


User GTI

Rise time bands

Energy bands

Uniformity map



ISGRI Contexts (pixels off, low-energy thresholds)

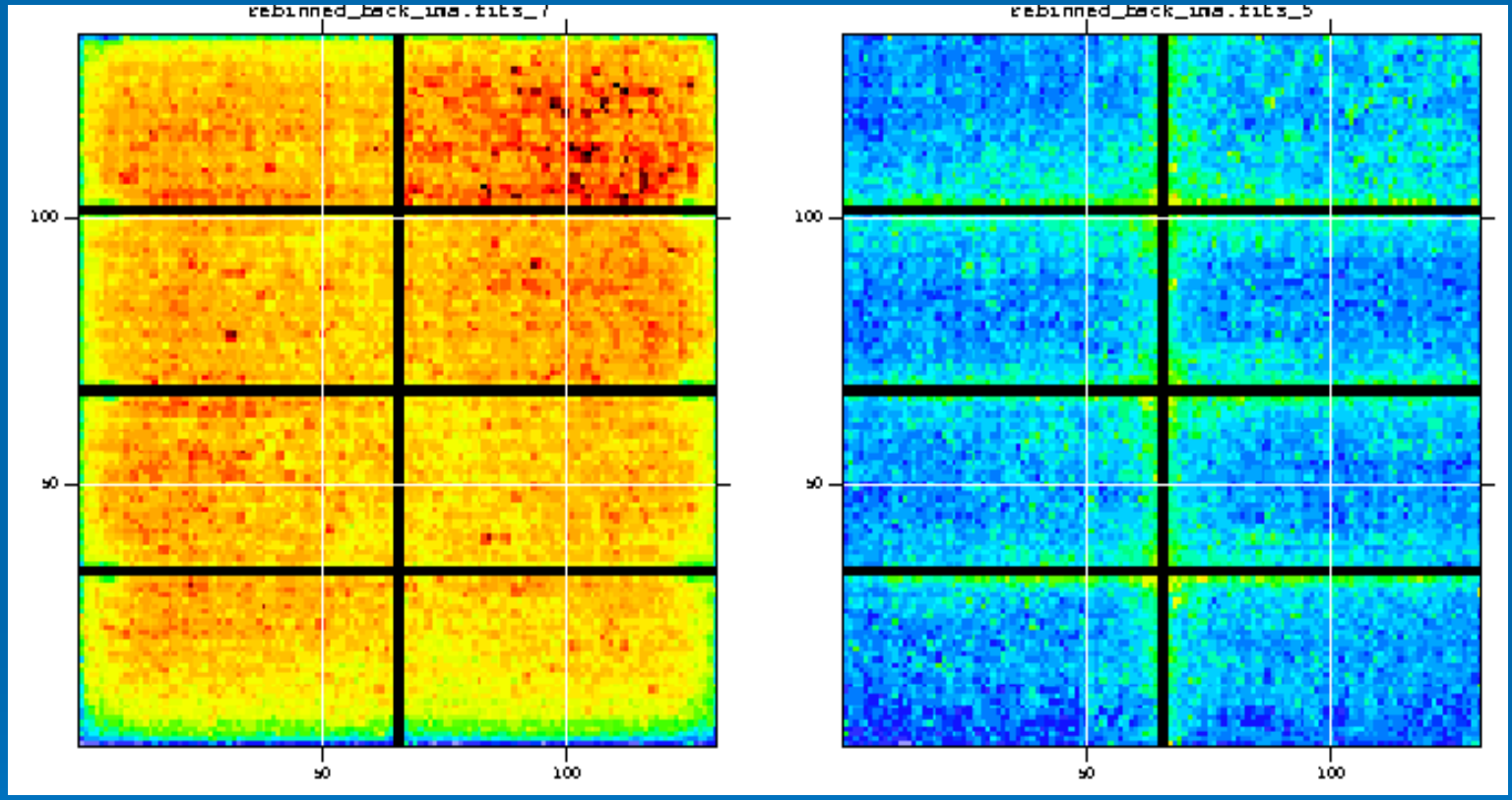
Dead-Times

GTIs

Background Correction Maps

80-120 keV

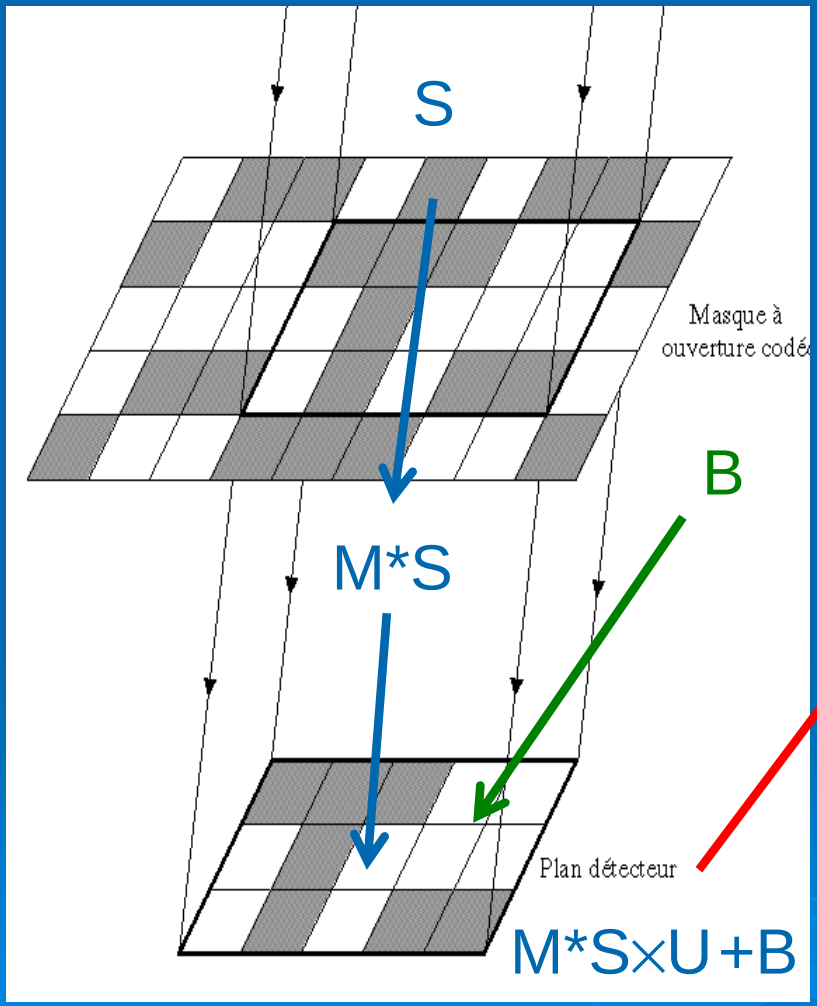
40-60 keV



Background images are built from large sample of empty field or high latitude pointing observations. Images are corrected for efficiency.

256 BKG correction shadowgrams (130 x134) for 256 energy channels.

Shadow Build – Uniformity Background Correction



$$D = (M * S \times U + B) \times E$$

$$M * S = \frac{\frac{D}{E} - B}{U}$$

D : detector image

M : Mask

S : Sky

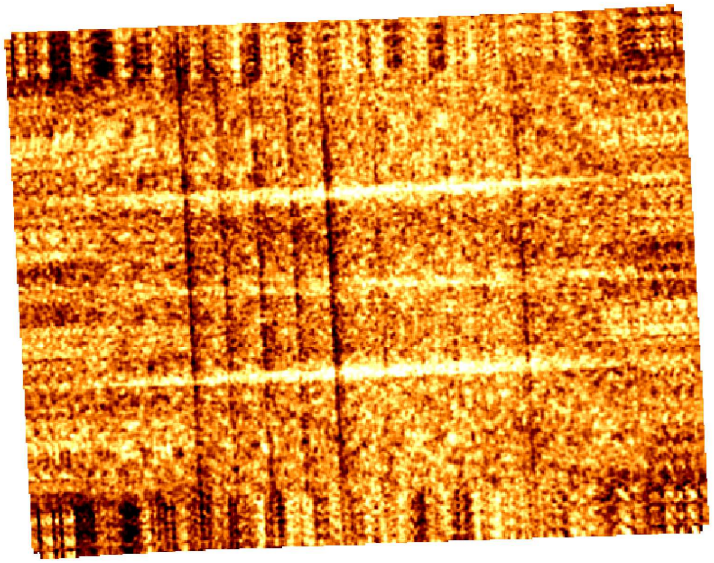
U: Uniformity

B : Background

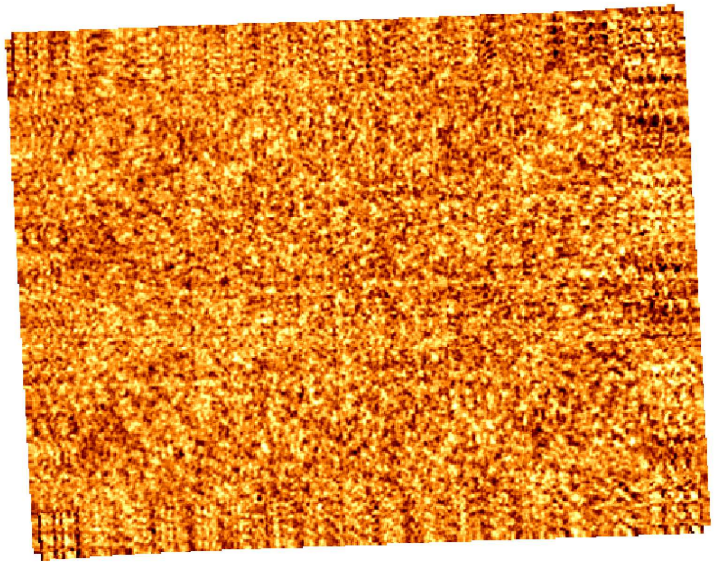
E : Efficiency.

Effect of Background Correction (100-200 keV)

not corrected



corrected

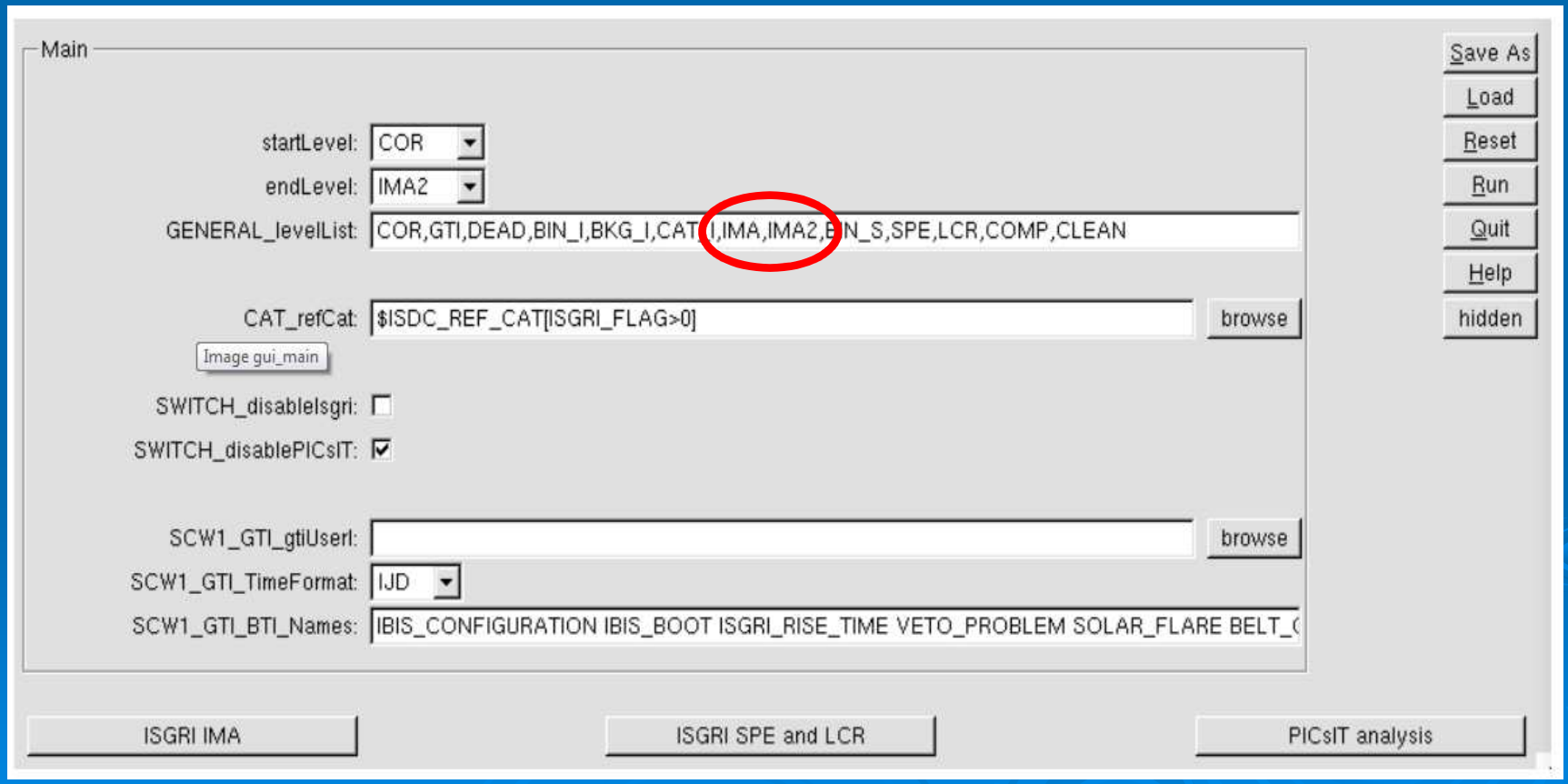


Mosaic of Galactic Center sky images (~ 5) before and after ubc correction

Some residual bkg noise present because correction maps are not perfect

Standard analysis Web Interface at ISDC

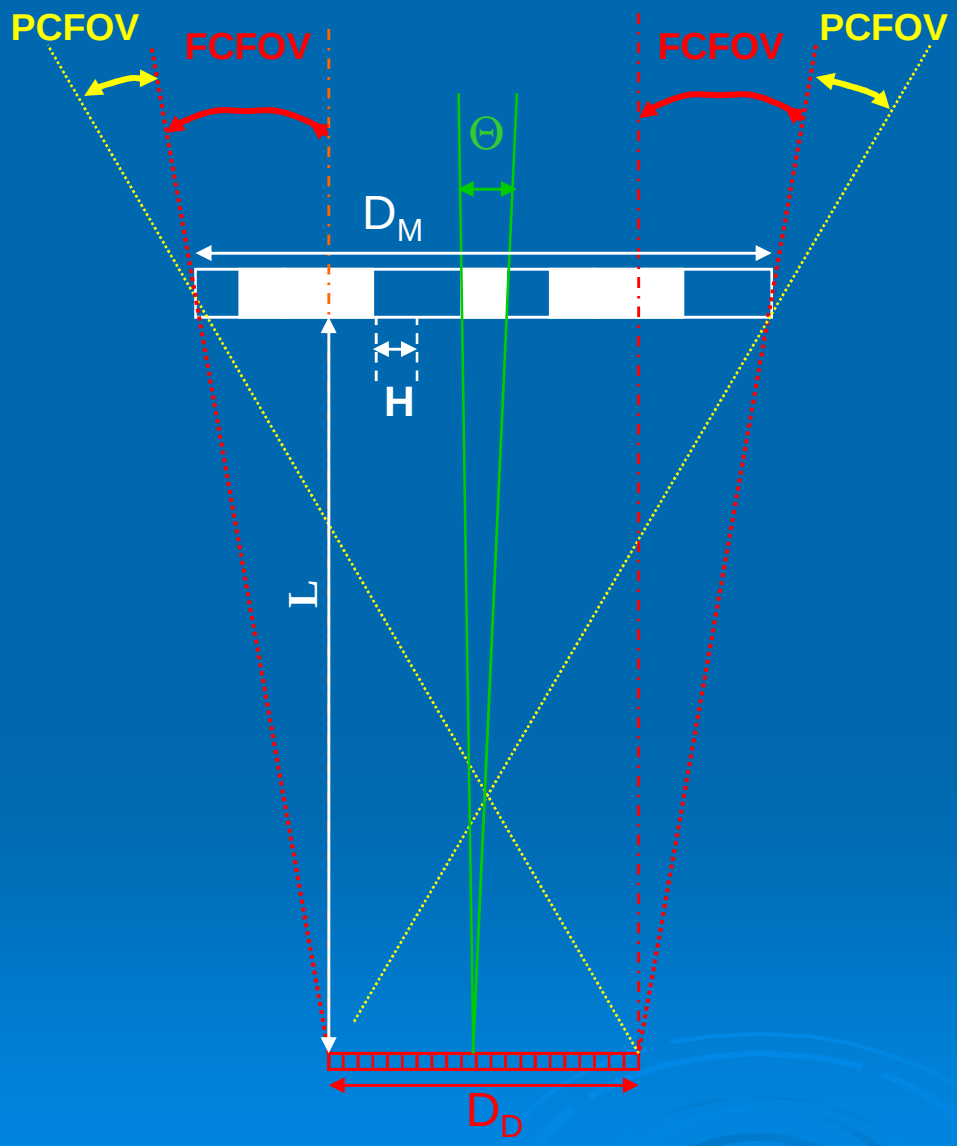
⇒ launching ibis_science_analysis …



IBIS data analysis:

5. Imaging

Coded Mask Imaging : Parameters



Mask

Opaque/transparent elements
Element size constant = H
Distance from detector = L
Mask dimension = D_M

Position Sensitive Detector

Dimension $D_D \leq$ mask dim D_M
Pixels size ≤ mask element size

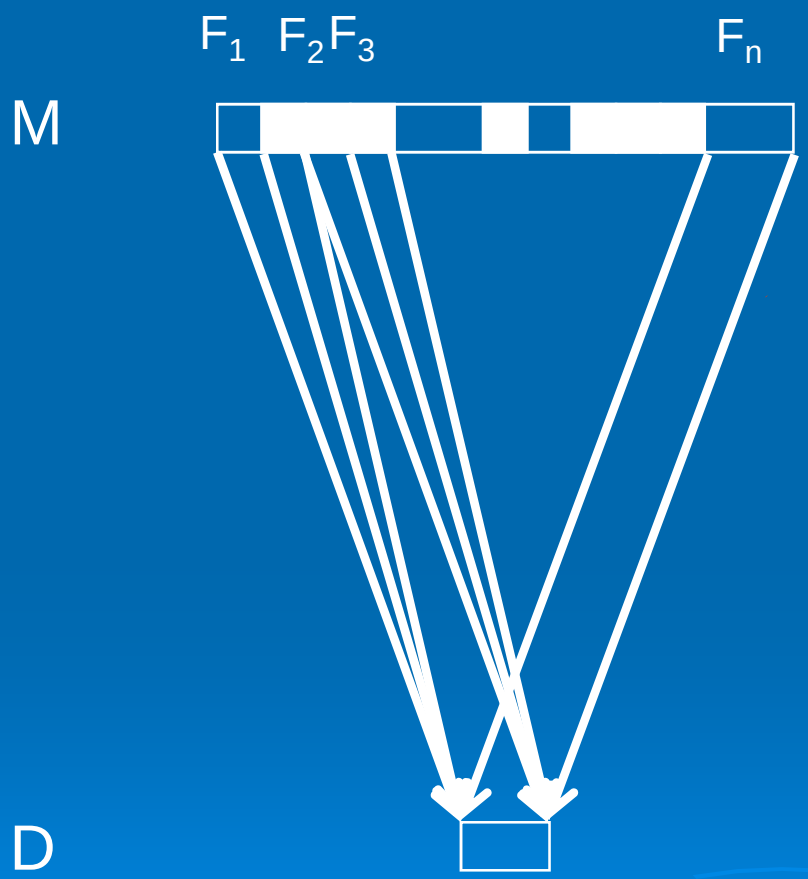
Two Fields of View

Fully Coded (sens. ~ const.)
$\Theta_{FC} = \text{arctg}((D_M - D_D) / L)$
Partially Coded (decr. sens.)
$\Theta_{PC} = \text{arctg}((D_M + D_D) / L)$

Angular Resolution

$\Theta = \text{arctg}(H/L)$

Coded Mask Imaging : Principles



$$
\begin{aligned}
& F_1 \times \{0\ \ 1\}\{M_1\ M_2\} \\
+\ & F_2 \times \{1\ \ 1\}\{M_2\ M_3\} \\
+\ & F_3 \times \{1\ \ 1\}\{M_3\ M_4\} \\
+\ & \ldots \\
+\ & F_{n-1} \times \{0\ \ 0\}\{M_{n-1}\ M_n\}
\end{aligned}
$$

$$D_j = \sum_i F_i M_{i+j}$$

$$\Rightarrow\ D_{ij} = \sum_{k,l} F_{kl} M_{i+k,j+l}$$

(convolution product)

Coded Mask Imaging : Coding & Decoding

Source flux (S) is modulated by mask (M) before being recorded by a position sensitive detector, the resulting image (D) is, if B is background :

$$D = S * M + B$$

If it exists G such that $G * M = \delta$ (= delta function), reconstructed sky S' is

$$S' = D * G = S * M * G - B * G = S * \delta - B * G = S - B * G$$

S' = S apart from the background term $B * G$, a constant level if B uniform.

Such array G exists for Uniformly Redundant Arrays (URA), built using cyclic different sets, binary sets with a cyclic autocorrelation function = δ

For URA $G = 2M - 1$ (-1 associated to opaque, +1 to transparent elem.).

Coded Mask Imaging : Errors and Noise

Statistical errors

URA (as Hadamard or other optimum masks) provide best statistical error since G = +1 or -1. Assuming Poissonian statistics of detector count rates:

$$V(S') = V(D * G) = G^2 * V(D) = V(D) = \text{Total number of detector counts } C$$

Source signal to noise ratio (S/N) for a measured source intensity I_S is then

$$S / N = I_S / V^{1/2} = I_S / (C)^{1/2}$$

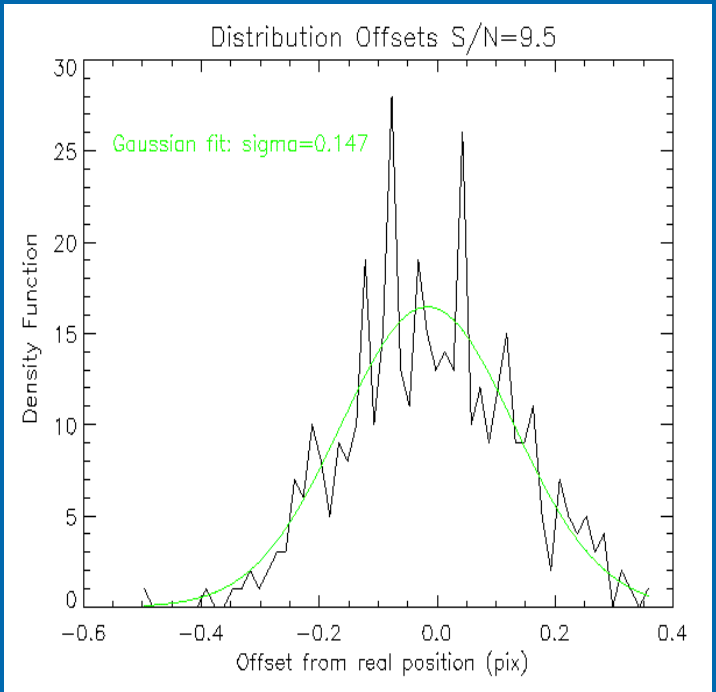
However any deviation from optimum system induce systematic errors.

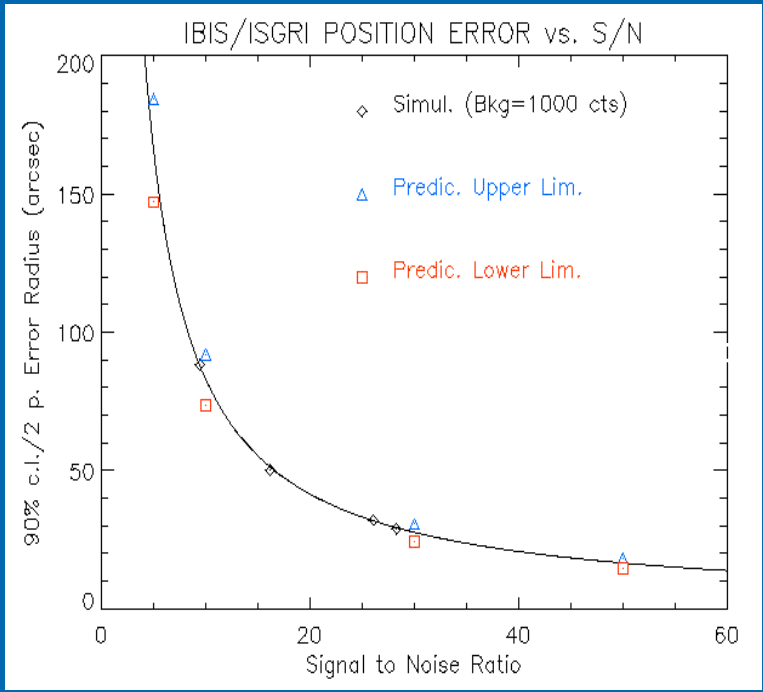
Systematic errors

The worse are those which **depend on the background**.
Condition B = uniform over detector plane is usually not verified.
In this case the decoding procedure magnifies the variations.
=> need to correct the non-uniform background spatial distribution

Other source of systematic noise is the ***non perfect coding*** (side lobes in the PSF) due to non-perfect system (dead zones, geometrical effect, etc.).
Coding noise is proportional to source flux.

Predicted IBIS Imaging Performances





IBIS Point Source Location Accuracy

Positional error (90% c.l.) as a function of the source S/N computed using simulations for r=2.43 and compared to theorical values computed for r = 1, 2.

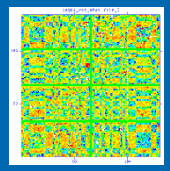
Positional error can be as low a 20” at S / N > 40 ≈ INTEGRAL attitude errors

OSA Imaging Iterative Procedure

RAW Data

Energy Corr
Deadtimes

COR Event List
Y1 z1 Pha1 RT1 E1
OBT1
Y2 z2 Pha2 RT2 E2
OBT2
Y3 z3 Pha3 RT3 E3
OBT3
.....
.....
Image Binning
Efficiency Map
Yn Zn PHn RTn En
OBTn



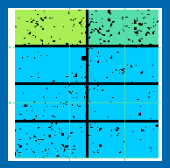
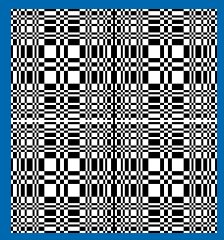
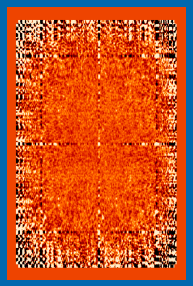


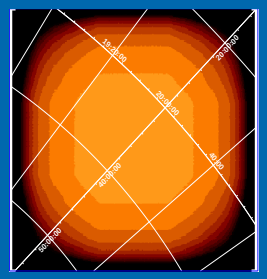
Image Unif.
Bkg
Corect.

Mask

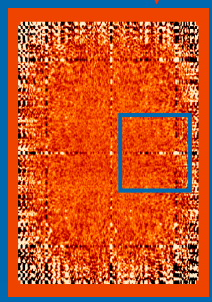


Decoding
Sky Image





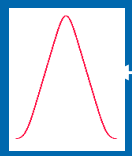
Source
Detection



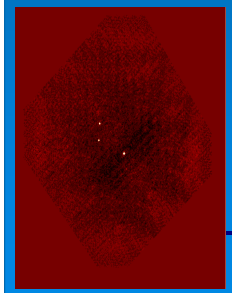
Loop on Sources

Source
Parameters

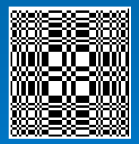
Source
Locat
(SPSF Fit)



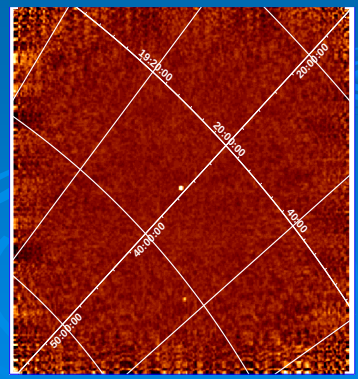
Mosaicked
Sky Image



Computing
Source
Model



Removal of
Source
Ghosts



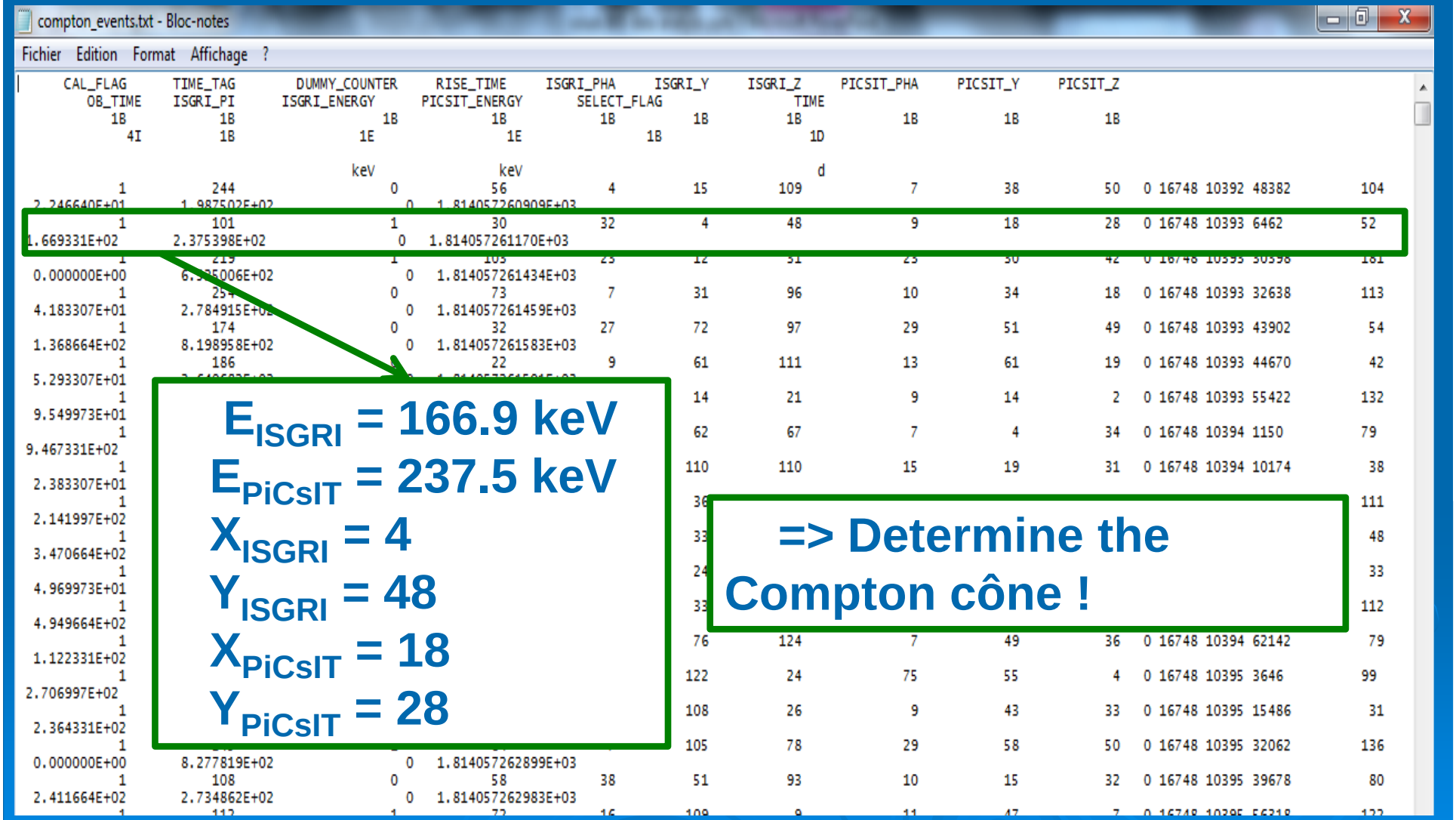
Mosaics of
Cleaned
Sky

Cleaned
Sky Image

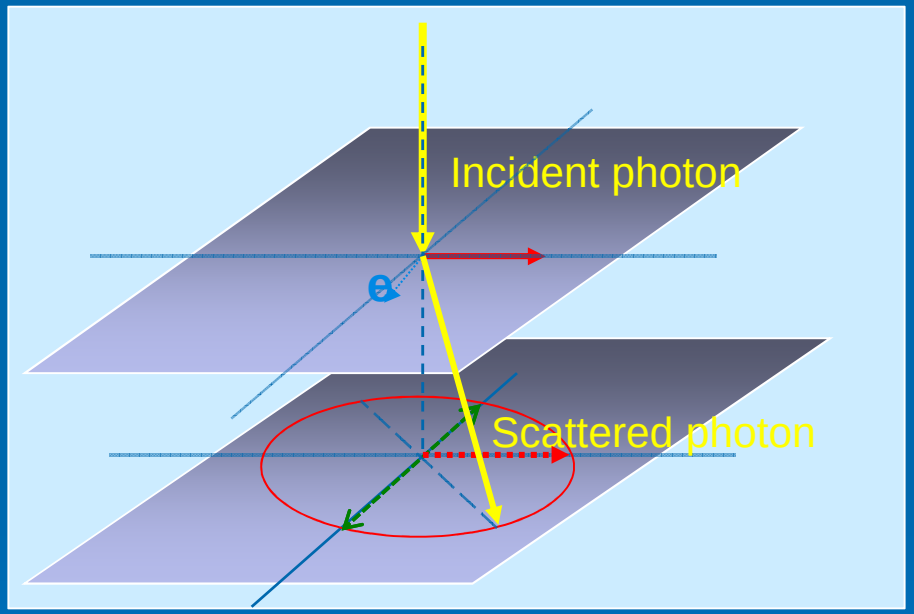
IBIS data analysis:

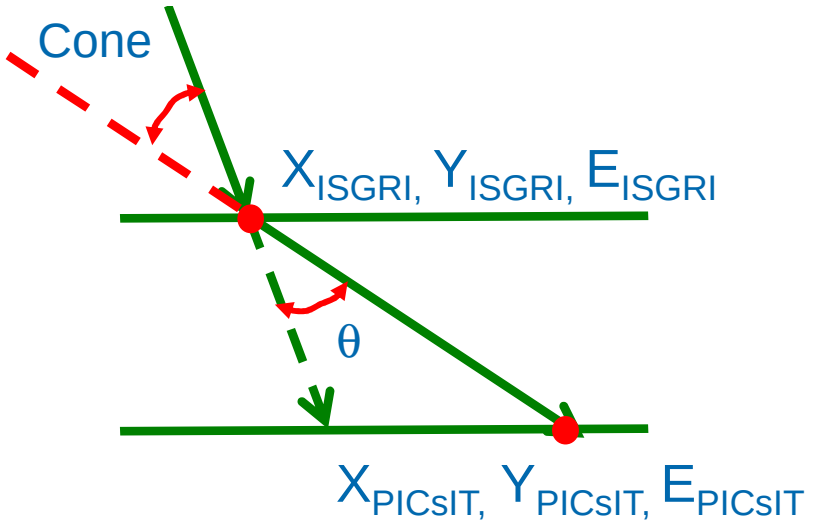
6. Compton imaging

First selected Compton event



Compton cones





$$E_0 = E_{PICsIT} + E_{ISGRI}$$

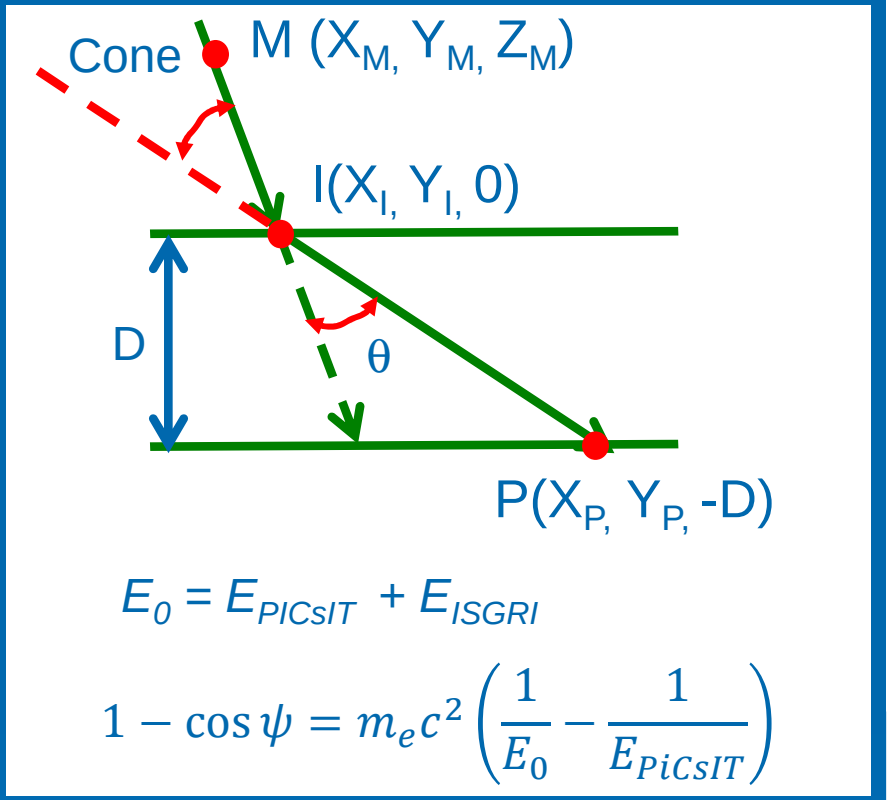
$$1 - \cos\psi = m_e c^2 \left(\frac{1}{E_0} - \frac{1}{E_{PiCsIT}} \right)$$

Compton cones

$X_I = 4.6\ X_{ISGRI}$ (mm)
$Y_I = 4.6\ Y_{ISGRI}$ (mm)

$X_P = 9.2\ X_{PiCsIT}$ (mm)
$Y_P = 9.2\ Y_{PiCsIT}$ (mm)

D = 10 mm



$E_0 = E_{PICsIT} + E_{ISGRI}$

$$1 - \cos\psi = m_e c^2 \left(\frac{1}{E_0} - \frac{1}{E_{PiCsIT}} \right)$$

$$\overrightarrow{PI} = \begin{pmatrix} X_I - X_P \\ Y_I - Y_P \\ D \end{pmatrix}$$

$$M \begin{pmatrix} X_M \\ Y_M \\ Z_M \end{pmatrix} \in cone \iff \overrightarrow{IM} \,.\, \overrightarrow{PI} = \left\| \overrightarrow{IM} \right\| \left\| \overrightarrow{PI} \right\| \cos\psi$$

$$\iff (X_M - X_I)(X_I - X_P) + (Y_M - Y_I)(Y_I - Y_P) + Z_M D = \left\| \overrightarrow{IM} \right\| \left\| \overrightarrow{PI} \right\| \cos\psi$$

Compton cones

$$(X_M - X_I)(X_I - X_P) + (Y_M - Y_I)(Y_I - Y_P) + Z_M D = \left\|\overrightarrow{IM}\right\| \left\|\overrightarrow{PI}\right\| \cos\psi$$

$$M \begin{pmatrix} X_M \\ Y_M \\ Z_M \end{pmatrix} \in \text{sphere radius } R \text{ center } I \Leftrightarrow \left\|\overrightarrow{IM}\right\| = R$$

$$\overrightarrow{IM} = \begin{pmatrix} R\cos\theta\cos\varphi \\ R\cos\theta\sin\varphi \\ R\sin\theta \end{pmatrix}$$

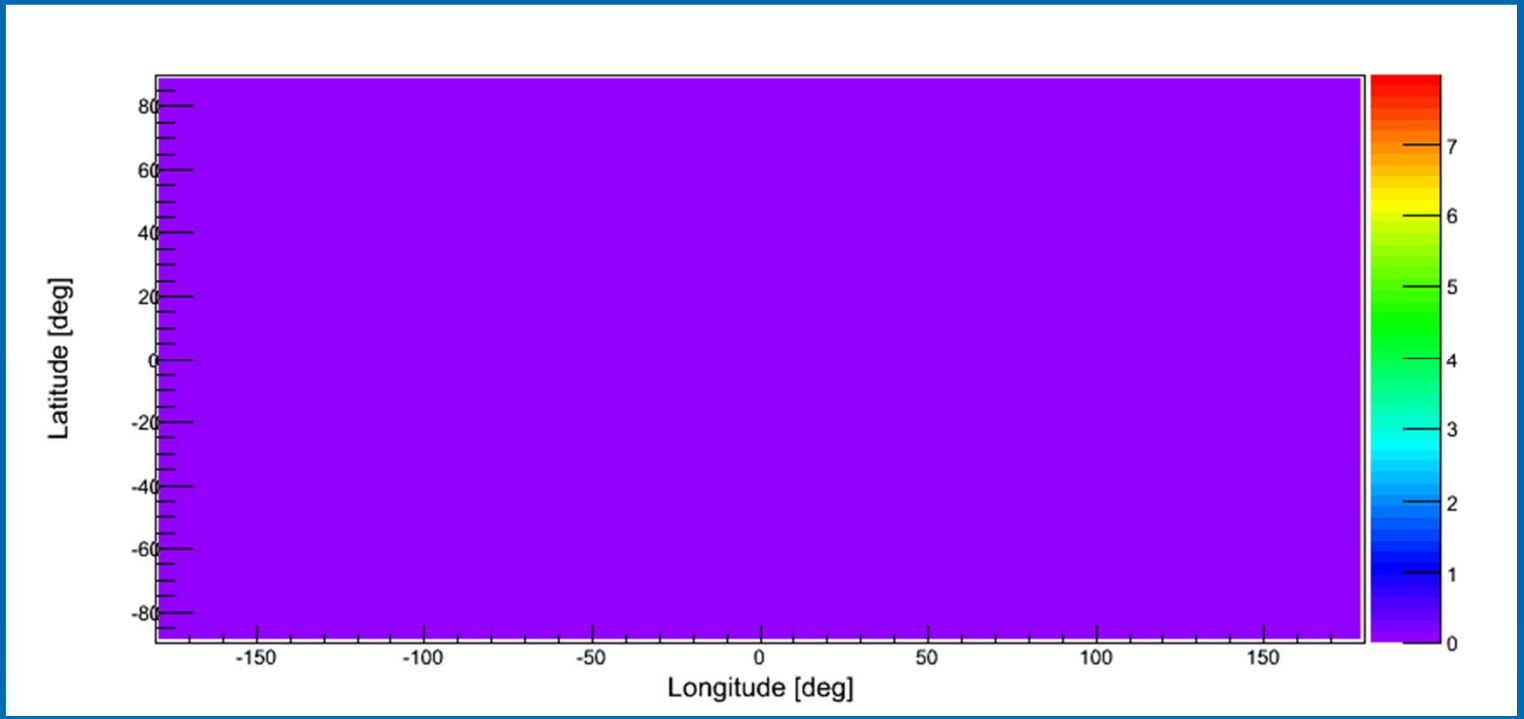
$$\boxed{\alpha\cos\theta\cos\varphi + \beta\cos\theta\sin\varphi + \sin\theta = \gamma}$$

$$\alpha = X_I - X_P$$

$$\beta = Y_I - Y_P$$

$$\gamma = \left\|\overrightarrow{PI}\right\| \cos\psi$$

Compton cones



projection des cônes

simulation done by gamma-ray astronomy group @ SSL (UC Berkeley)

Thank you !