IBIS/ISGRI Data Analysis

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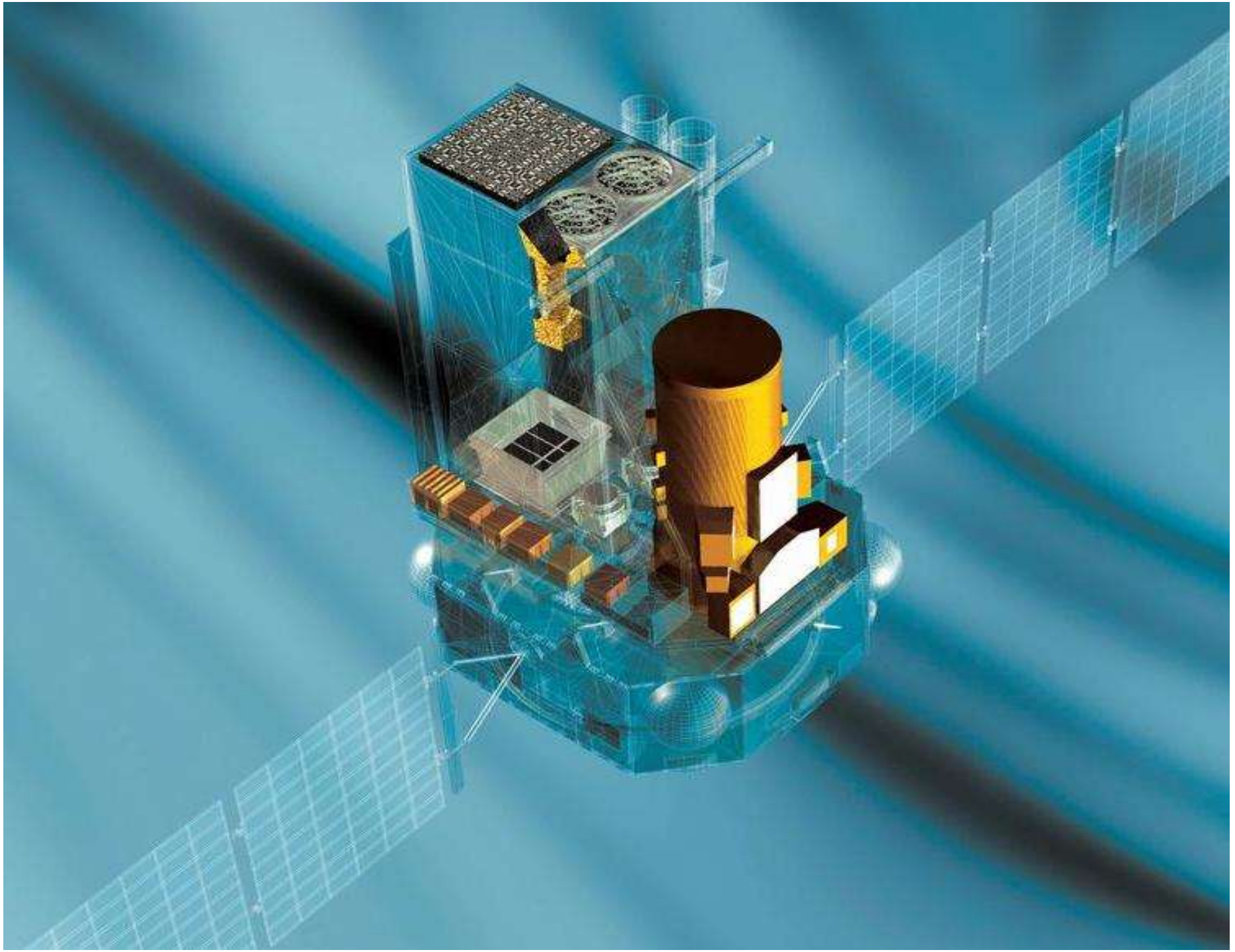
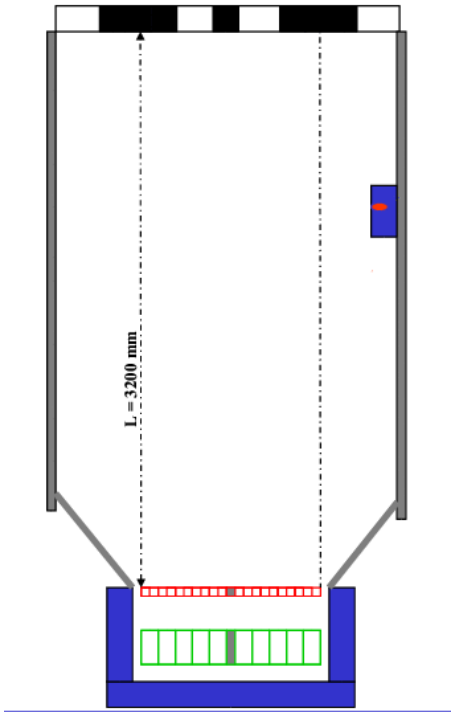
Presentation includes materials taken from
A. Paizis, A. Goldworum, P. Kretschmar, P. Lubinski

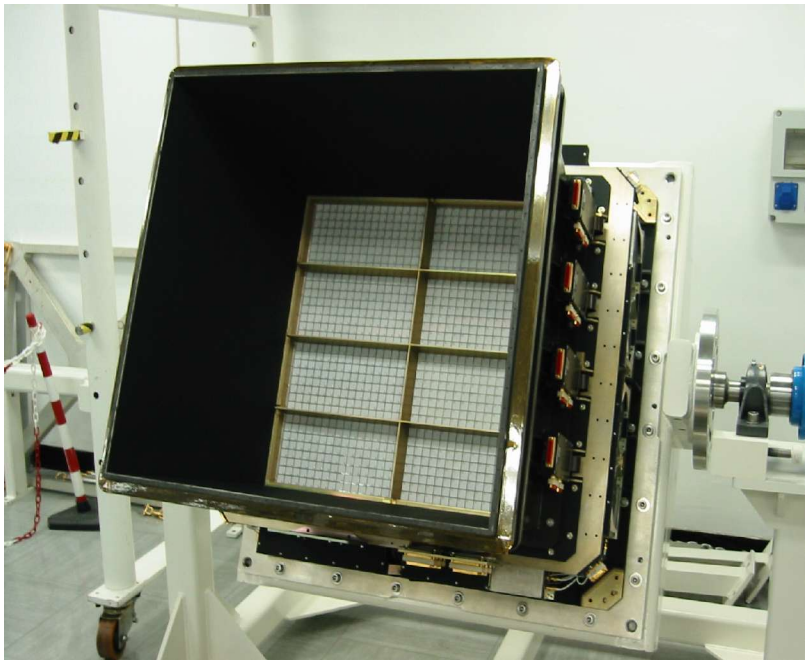
- The IBIS instrument
- OSA: behind the scenes
- Hands-on tutorial
- What else?

INTEGRAL Data Analysis Workshop
October 18-20, 2006, ISDC



The IBIS instrument





Mask :
95×95 square cells 11.2×11.2 mm^2.
Half of the mask cells are opaque to photons (70% opacity at 1.5 MeV).
The other 50% of cells are open, off-axis transparency of 60% at 20 keV.

Support Panel
is done from the material known as nomex . Its transparency should be taken into account in the data analysis, as it absorbs part of the flux.

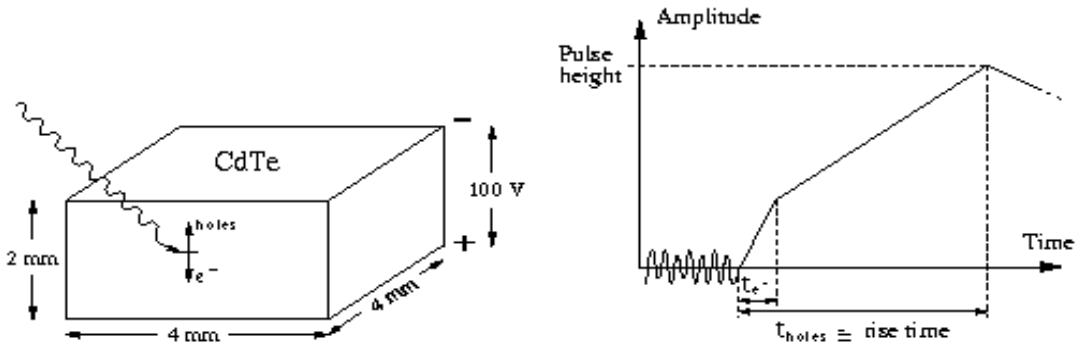
Positional Detectors :
ISGRI (CdTe): 15 keV – 1 MeV
PICsIT (CsI): 170 keV – 10 MeV

Shielding system, Veto and CU :
Passive (tube, hopper)
Veto Unit : 16 BGO mod
Calibration Unit :
^{22}Na Source (511 keV, 1275 keV)

How the detector works

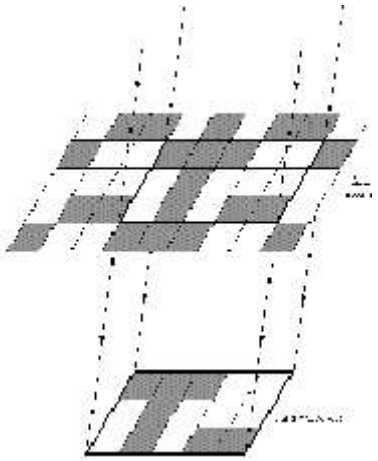
Cadmium Telluride (CdTe) is a semiconductor operating at ambient temperature (0 - 20 C°). The photon entering the telescope can be detected due to its interaction with the absorbing material of the detector (photoelectric absorption, Compton scattering and pair production). In the photoelectric absorption process a an energetic photoelectron is ejected by the atom, carrying away most of the original photon energy.

Due the charge loss in the CdTe crystal, for a given energy deposit, events which have interacted at different depths in the crystal get different measured amplitudes. The rise-time of the signal induced by these events is also different, and a clear quasi-linear correlation between the charge loss and the rise-time variation is observed.

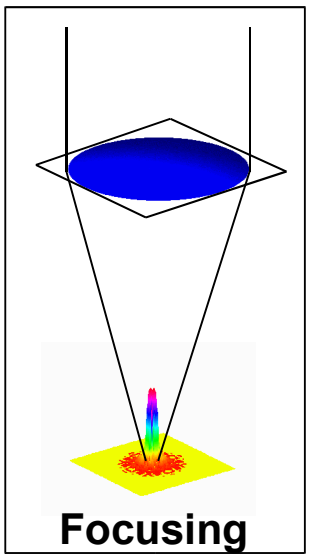


Using calibrated correction tables (Look Up Tables) an energy is computed and corrected for the charge loss effect for each recorded event.
LUT 1 is used to correct for gain and offset of Pulse Height Amplitude and Rise Time.
LUT 2 is used to correct for the charge loss.

Coded mask imaging – some background



Coded Mask



Coded Aperture Systems employ a mask of opaque and transparent elements to modulate sky radiation before it is recorded by a position sensitive detector. Sources project patterns of the mask on the detector (pinhole camera concept), and an image can then be reconstructed by correlation with the known mask.

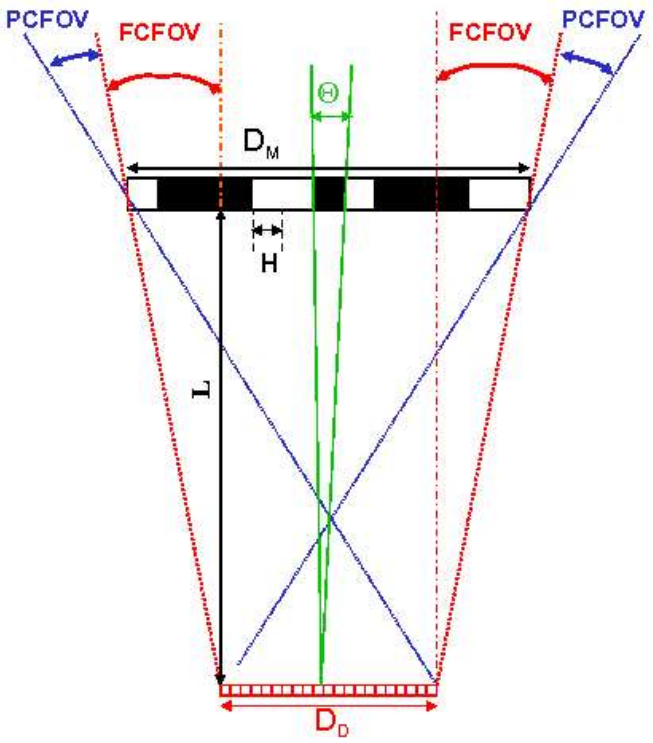
To reconstruct a sky image the mask pattern must be such that

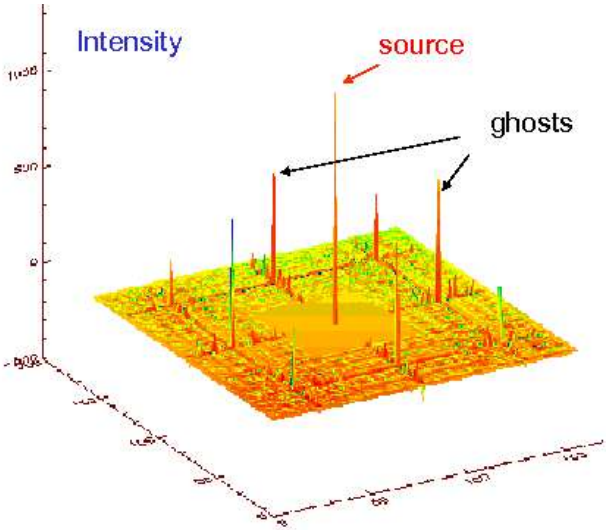
- the projected shadow by any given source must be unique

- the match between shifted patterns must be as poorest as possible

- **Worst imaginable PSF**
  - **Fills detector plane for a point source**
    $\Rightarrow$ Multiple sources are normally entangled!
  - **Also background relevant in whole detector!**
- **So why bother?**
  - **Images in energy range too high for focusing and too low for Compton or Tracking.**
  - **Wide fields of view and very good angular resolution.**
  - **Best energy resolution.**

Coded Mask Imaging : Choices and Parameters





- **If mask is larger than detector with cyclically replicated mask pattern (IBIS):**

  Two Fields of View:

  Fully Coded (sens. ~ const.)

  $\Theta_{FC} = \text{arctg}((D_M - D_D) / L)$

  Partially Coded (decr. sens.)

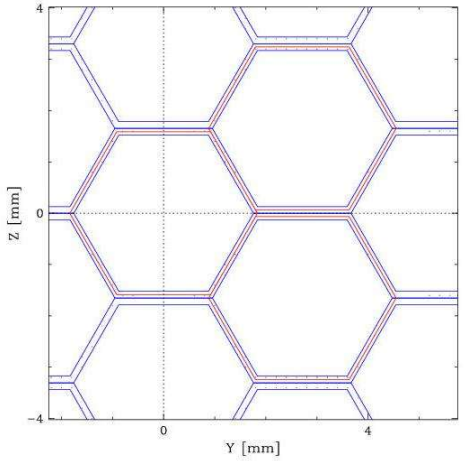
  $\Theta_{FC} = \text{arctg}((D_M - D_D) / L)$

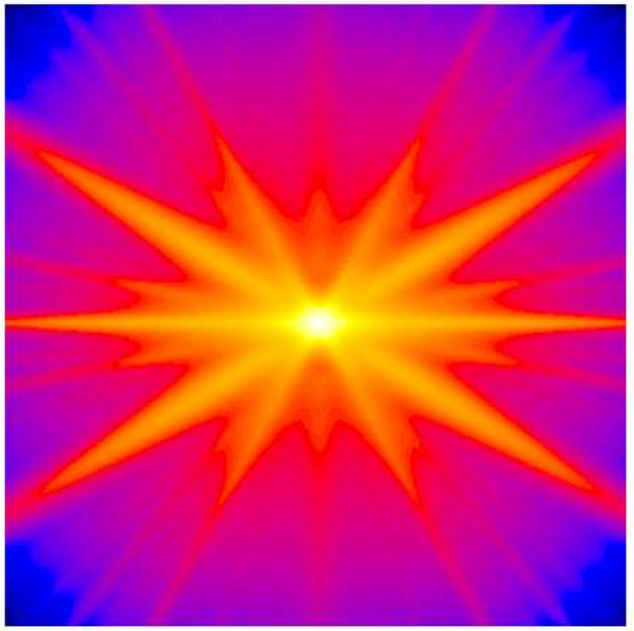
  Angular Resolution $\Theta = \text{arctg}(H/L)$

  - **Perfect reconstruction in Fully Coded FOV .**
  - ***But* 'ghosts' in Partially Coded FOV and sharp distinction between fully and partially coded.**

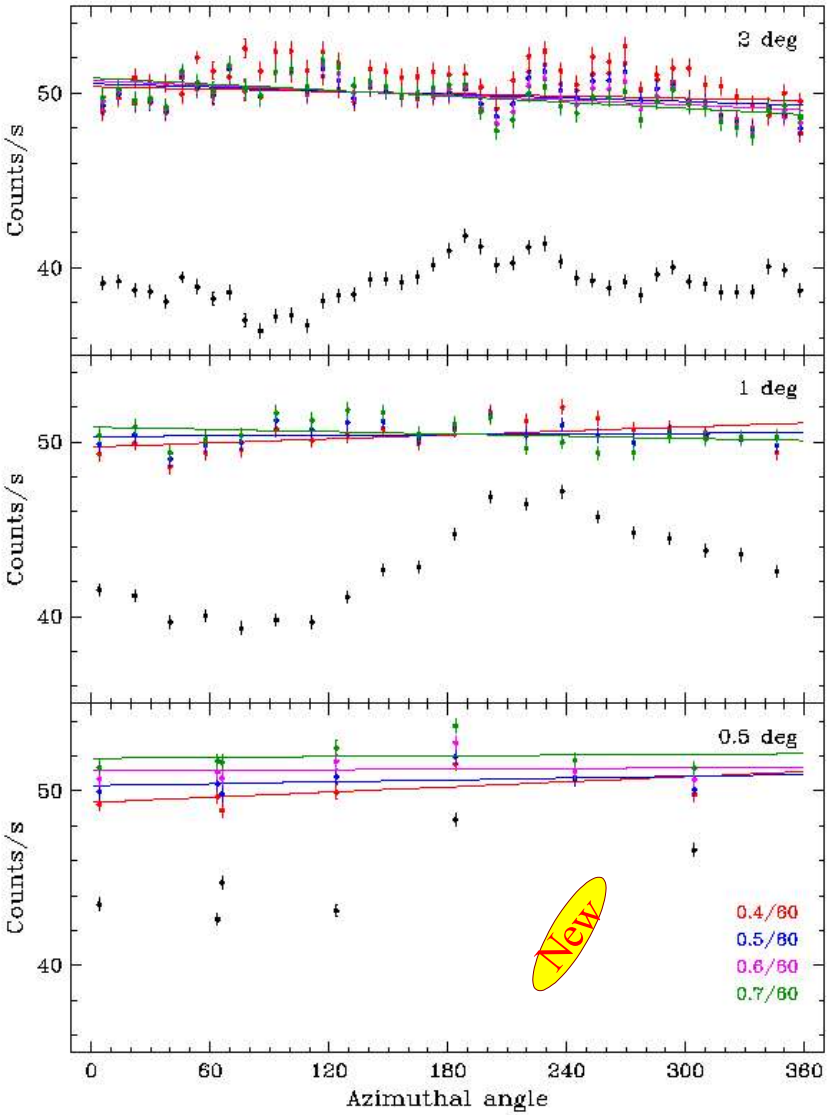
- **'Simple' design with mask equal to detector size and no repetition (JEM-X):**
  - **Reconstruction quality drops off gradually from on-axis position.**
  - **No 'ghosts' in PCFOV.**

Support Structure: NOMEX correction



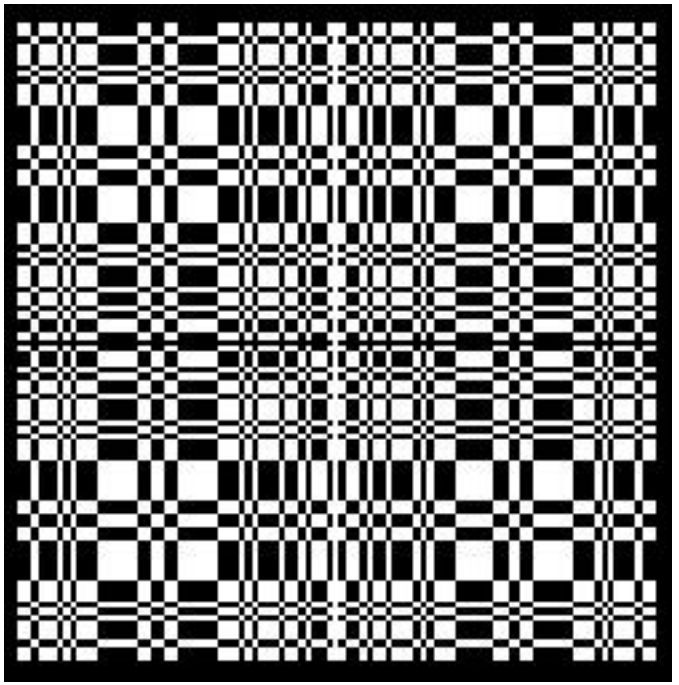


Transparency map in 23.29 – 24.25 keV range



Crab off-axis behaviour in 20 - 25 keV range, and its dependence on the tilt of the NOMEX

The IBIS instrument: Summary



Mask:
53 x 53 Modified Uniformly Redundant Array (MURA) basic pattern, i.e.
it exists G such that G * M = δ

Positional Detectors:
ISGRI (CdTe): 15 keV – 1 MeV
PICsIT (CsI): 170 keV – 10 MeV

Imaging properties:

FCFOV	9° x 9°
FC+PCFOV	29° x 29°
Angular Resolution	12’
ISGRI/PICsIT pixels	5’ / 10’

Sensitivity:
6 E-7 ph/sec cm2 keV @ 100keV
($\Delta E=E/2$, 3σ, 10^6 sec)

Spectral Resolution
8 keV @ 100 keV (FWHM)

OSA: behind the scenes

I	COR GTI DEAD	• Prepare the data for scientific analysis
II	BIN_I BKG_I CAT_I IMA	• Extract images and build up mosaics • ~Optional
III	BIN_S SPE	• Extract spectra • ~Optional
IV	LCR	• Extract lightcurves • Optional

There is a script that does all the above for you: *ibis_science_analysis*
You choose start, end and intermediate steps.

I - Prepare the data

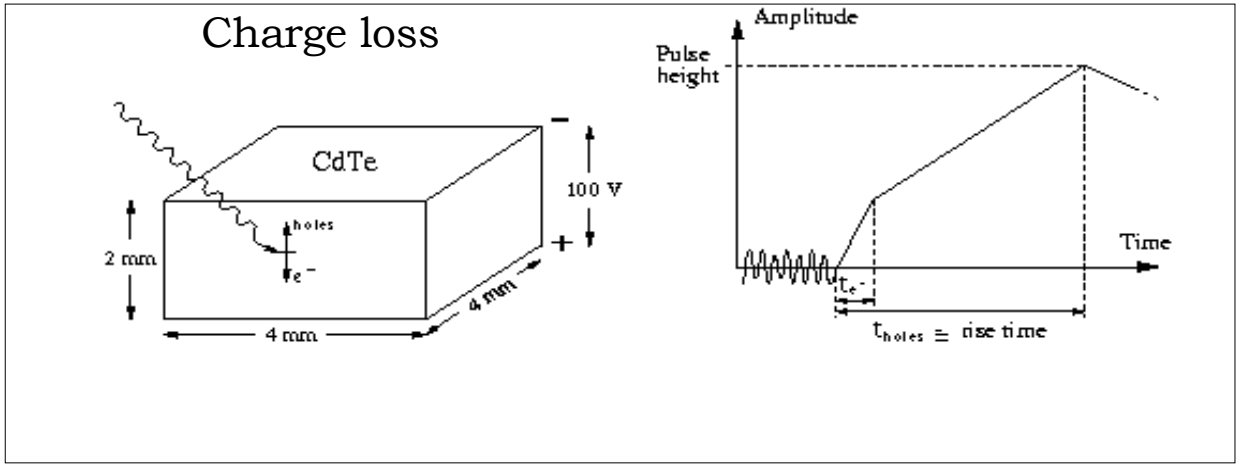
- COR
  - Tags noisy pixels
  - Computes the deposited energy of the events
- GTI
  - Extracts good time interval information and merges it (HK data, satellite stability, data gaps)
  - Excludes science windows from the predefined BTI list
    - IBIS_CONFIGURATION is to flag the change of configuration.
    - ISGRI_RISE_TIME indicates that on-board cut on rise-time is too low, so there are no arf and rmf for this case.
    - BELT_CROSSING indicates that belts are seen in VETO or ISGRI count-rates.
    - SOLAR_FLARE only 3 biggest ones
    - VETO_PROBLEM periods when VETO had count-rate much lower (or higher) than expected.
    - IBIS_BOOT indicates that IBIS has been restarted from OFF state unexpectedly.
    - MISCELLANEOUS For the moment most of the events are related to the drop of PICsIT counters.

New

- DEAD
  - Computes dead time (instrument, veto, calibration)

I - Prepare the data

- COR
  - Tags noisy pixels.
  - Computes the deposited energy of the events.



- GTI
  - Extracts good time interval information and merges it (HK data, satellite stability, data gaps)

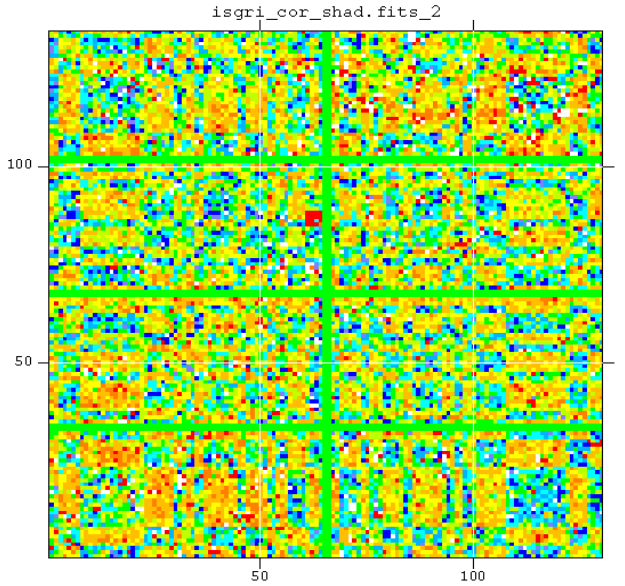
- DEAD
  - Computes dead time (instrument, veto, calibration)

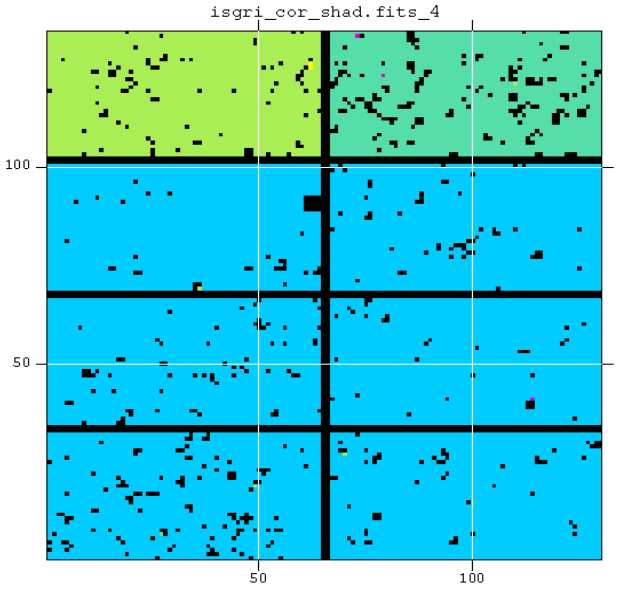
II - Images

- BIN_I
  - Creates shadowgrams in Ebins
  - Rebins background and Off-axis correction maps *New*
  - Computes efficiency maps in Ebins

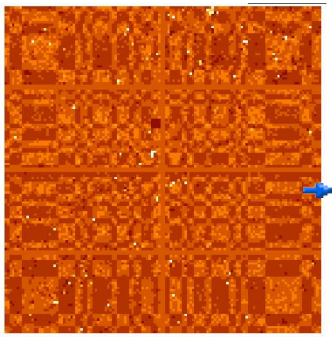
    Eff [Tbin,Ebin,y,z]=
    (1-D[Tbin,mdu]) * LT[Ebin,y,z].

    LT reflects the efficiency energy dependence due to the low threshold operation limit,





- BKG_I
  - Use background maps (prepared on the base of empty field observations) to obtain a “correct” shadowgram.

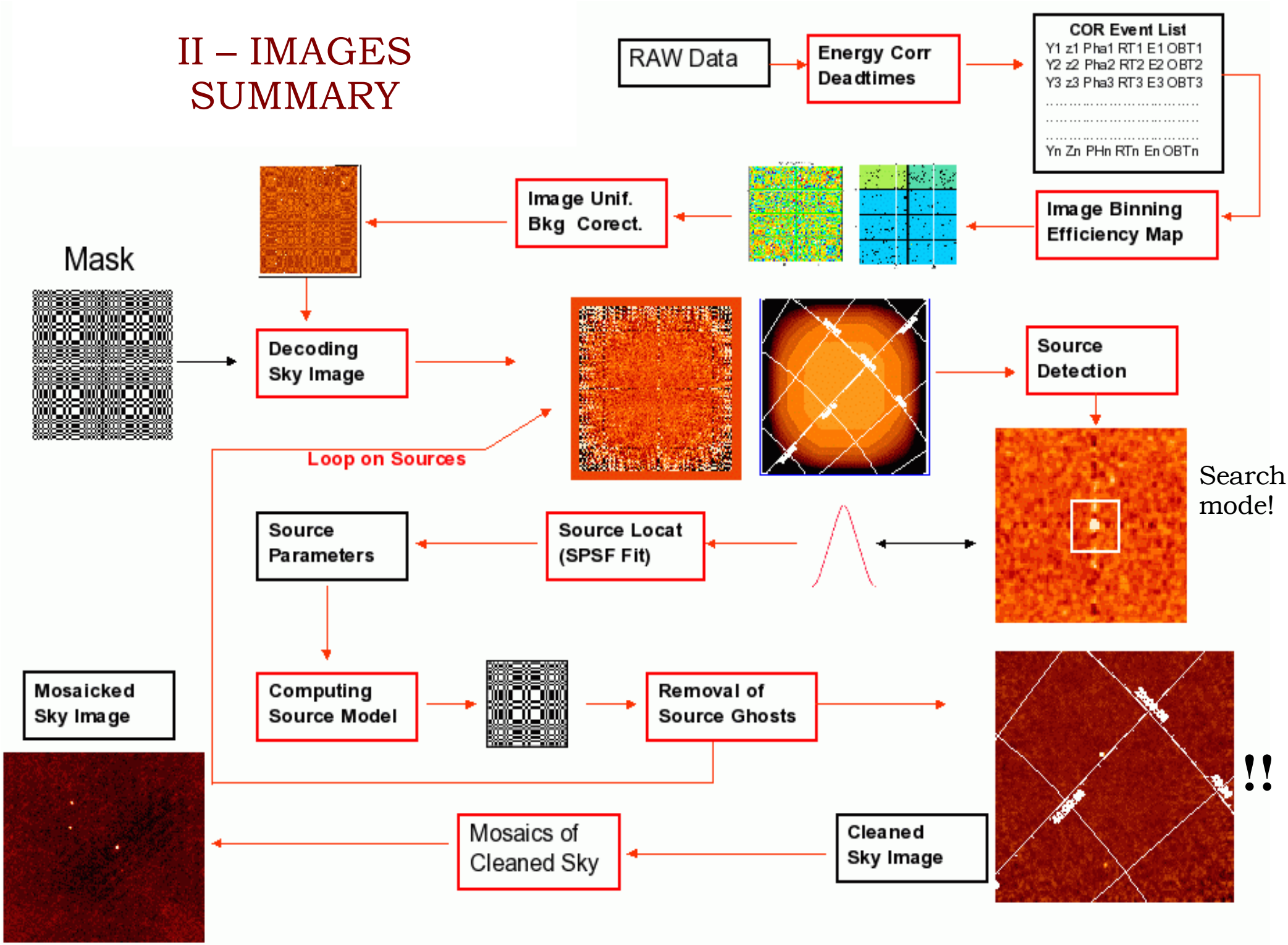


  - NEW
  - The background normalization is calculated from the shadowgrams from which the pixels affected by the photons from all sources previously detected by ISGRI with catalog flux in the 20 - 60 keV energy band is higher than 10 cts/sec (60 mCrabs) were removed.
  - Sometimes when you are not satisfied with the quality of your image you may want to try to redo the analysis without the background map subtraction.

- CAT_I
  - Create a catalogue with sources in the FOV

- IMA
  - Sky image reconstruction
  - Source search
  - Mosaic images

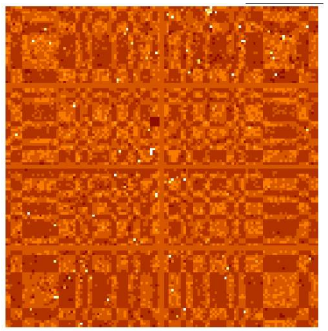
II – IMAGES SUMMARY



III - Spectra

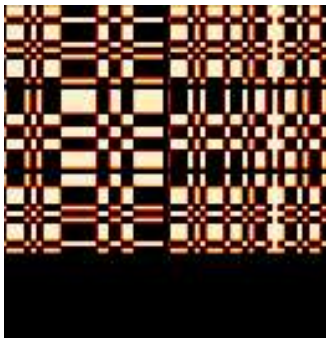
- BIN_S
  - Shadowgrams, background, off-axis and efficiency maps in new Ebins

- SPE



+ source list from the image step

  - **For each active source in the FOV** (catalog from imaging) it builds a model of the source contribution in each energy band (PIF)



Pixel Illuminated Function

time consuming!

PIF Source_1 PIF Source_2 ...

  - Extract spectra of the sources and background

IV Lightcurves

LCR

- You need PIF from SPE level
- Same as in SPE part with Tbin!

Summary of analysis levels

Launch the script that performs the following

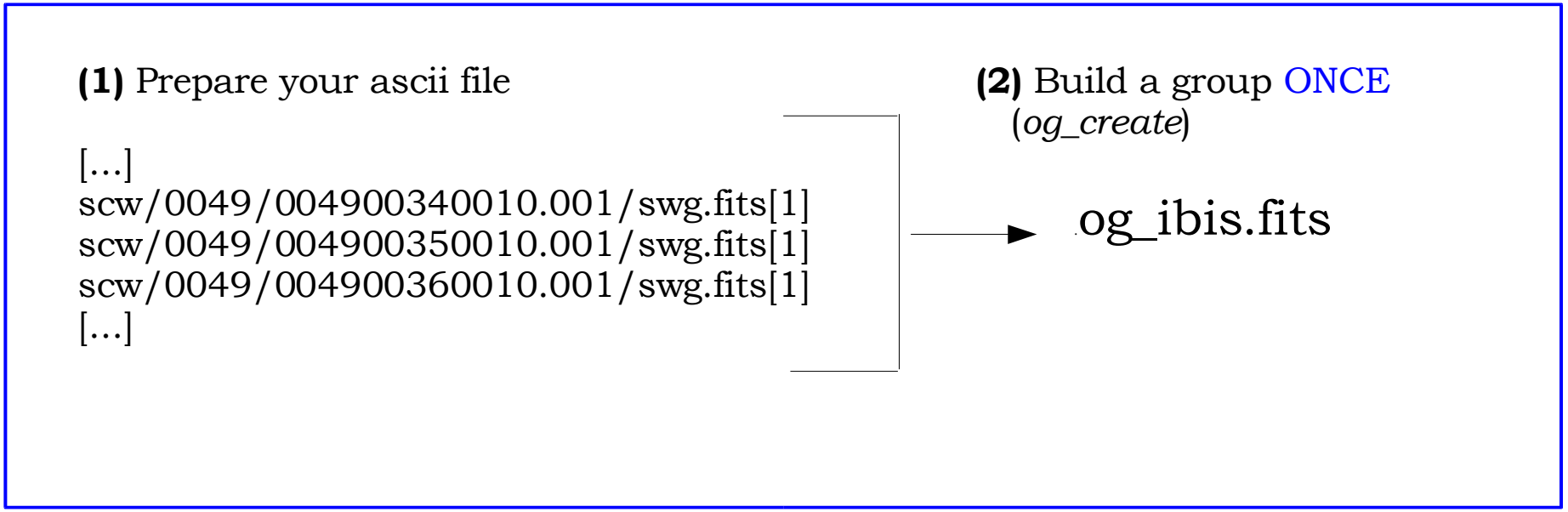
- "Prepares" the data: COR-GTI-DEAD
- Extracts images and source list
- Uses IMA source list (manually modified) to extract SPE
- Uses PIF (SPE) to run LCR

Do this during the hands-on session!

Hands-on tutorial

[0] Set up the environment (follow the commands given in the cookbook)

[A] BUILD A GROUP



Call the ascii file rev49_isgri

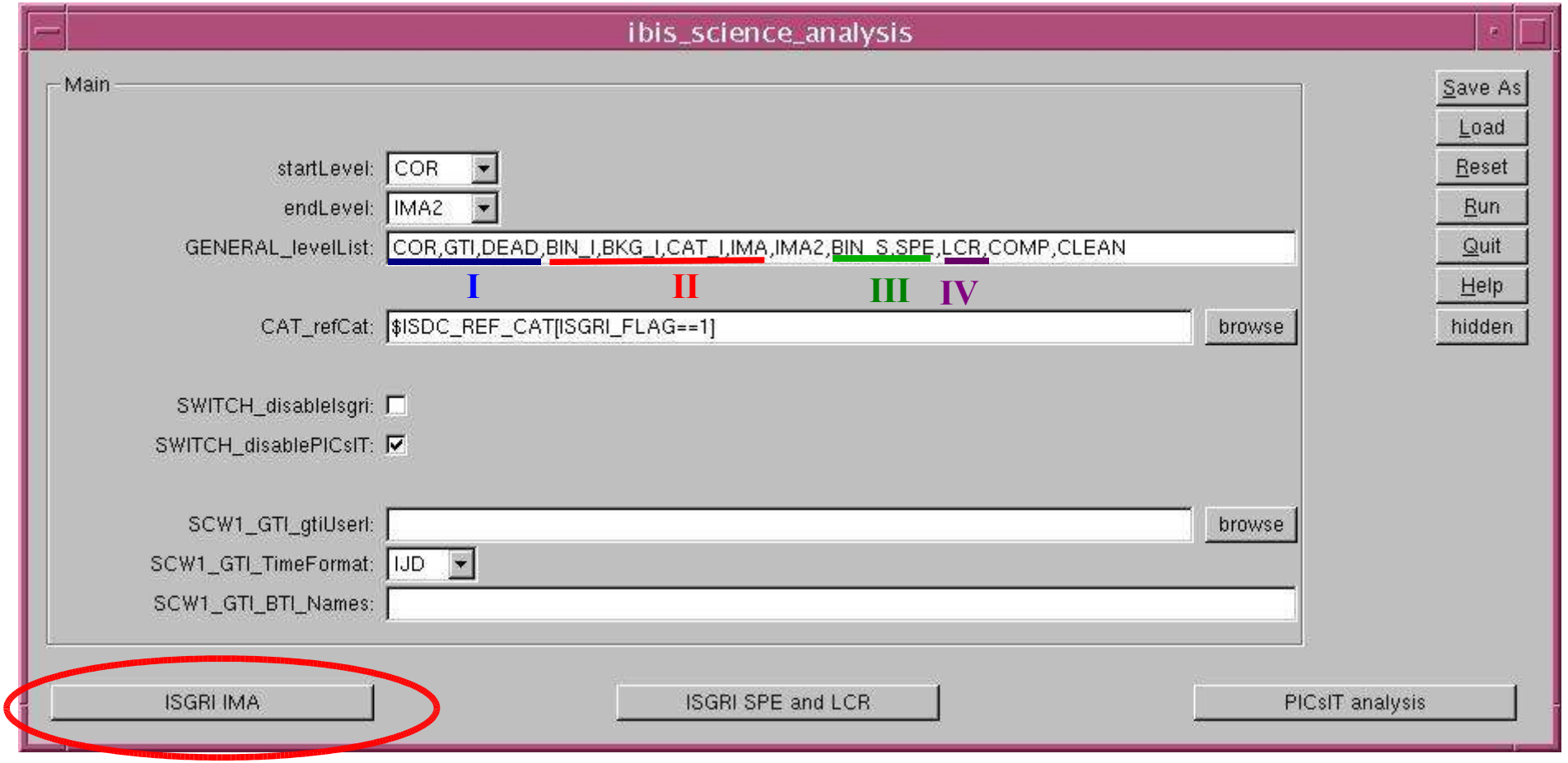
and

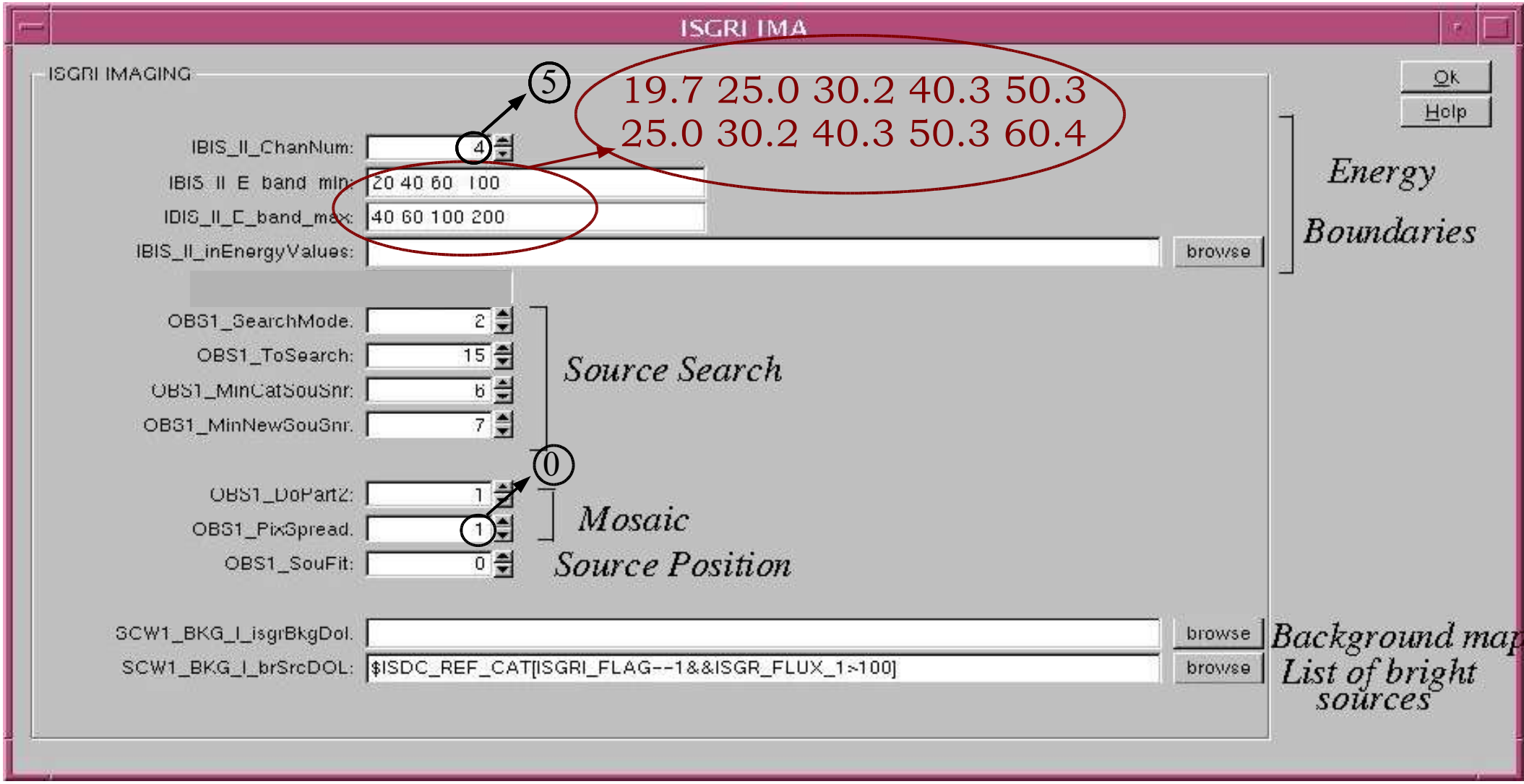
og_create idxSwg=rev49_isgri ogid=rev49_isgri baseDir="./" instrument=IBIS

cd obs/rev49_isgri.txt

[B] Launch till the IMA step

ibis_science_analysis





Press “OK” and on the main GUI, “Save” and “Run”

Results:

- each pointing
  isgri_sky_ima.fits
  isgri_sky_res.fits

- mosaic
  isgri_mosa_ima.fits
  isgri_mosa_res.fits

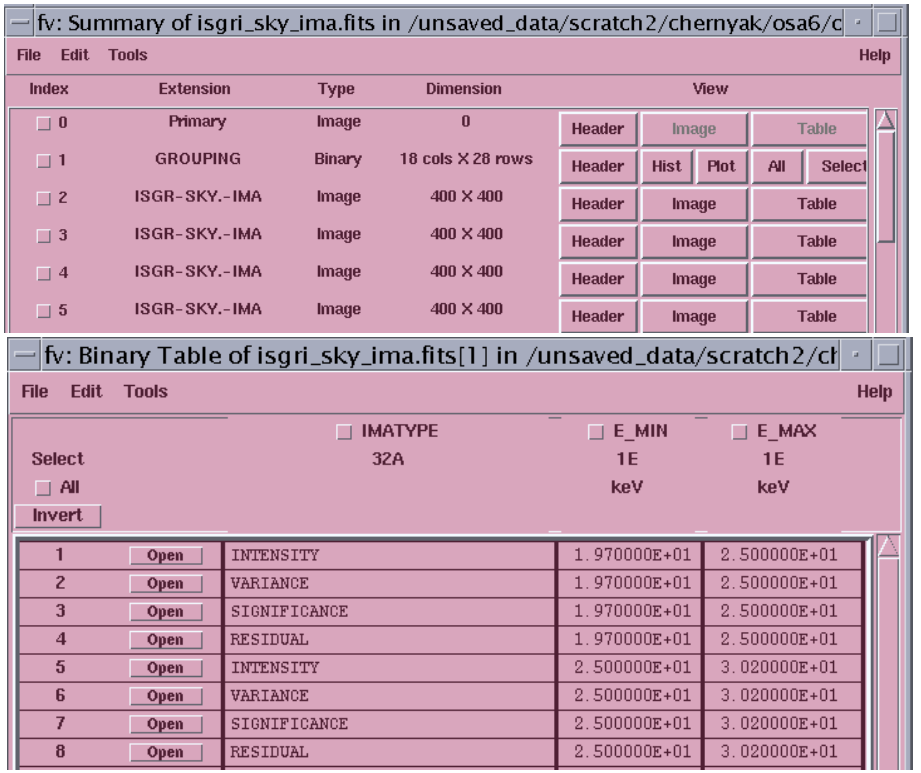
You need info from “sky” and “mosa”!!!

- Summary and “average”

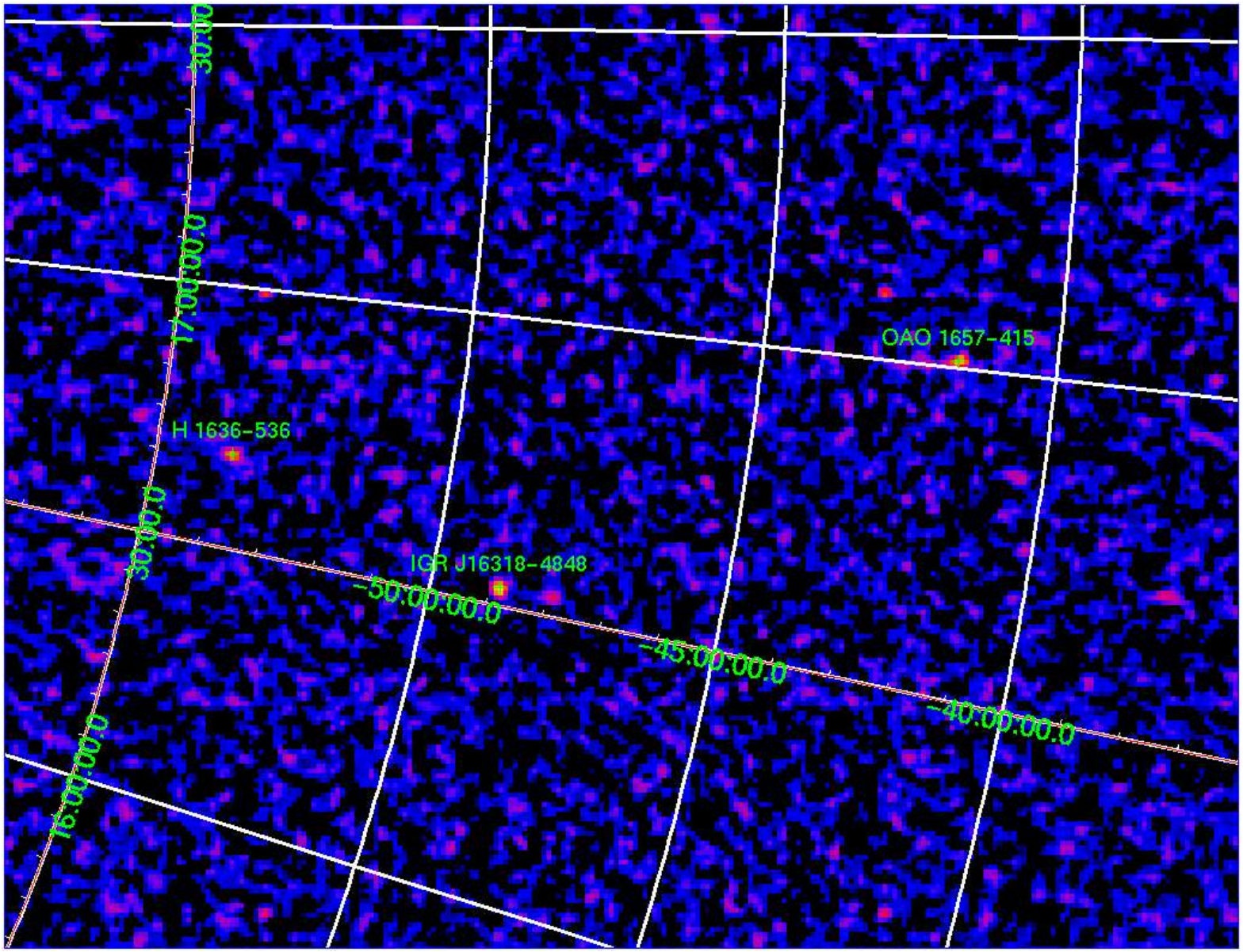
  isgri_srcl_res.fits

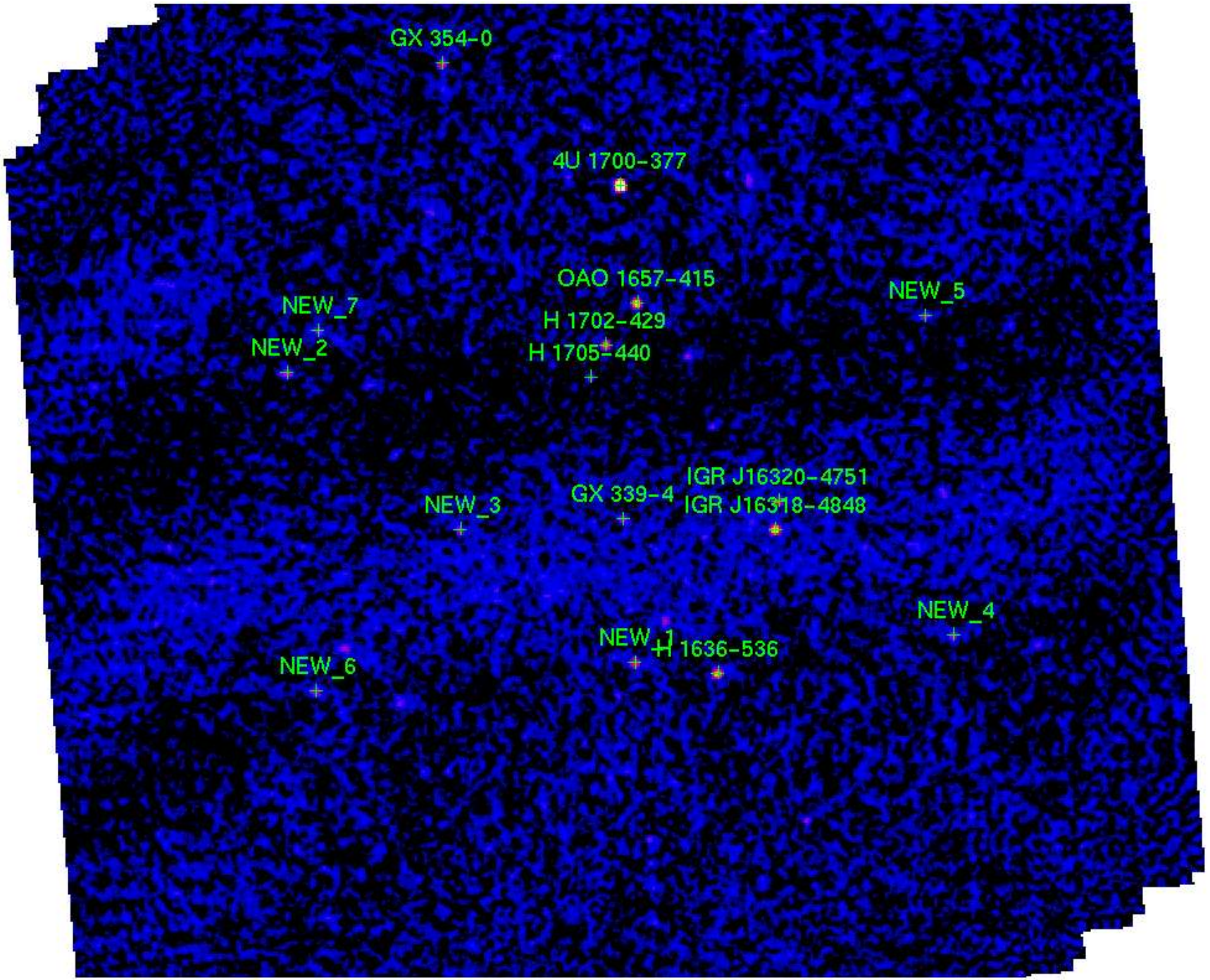
  This file contains all sources in the FOV (detected or not) with results for the detected sources.
  Could be 80 sources with only 10 detected (check DETSIG!!!).

fv isgri_sky_ima.fits

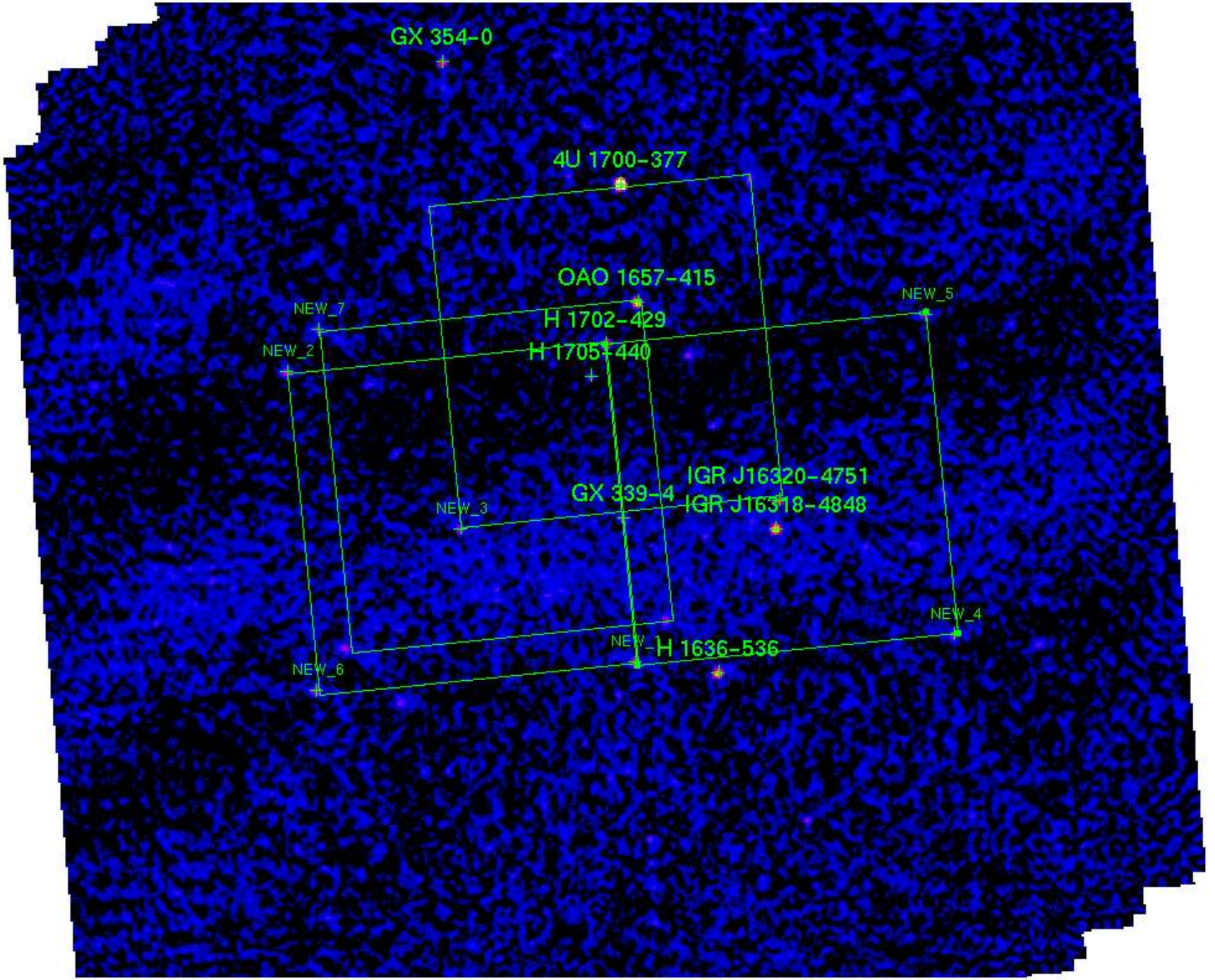


1 scw: 3 sources
30.2-40.3 keV





Mosaic: 16 sources
30.2-40.2 keV



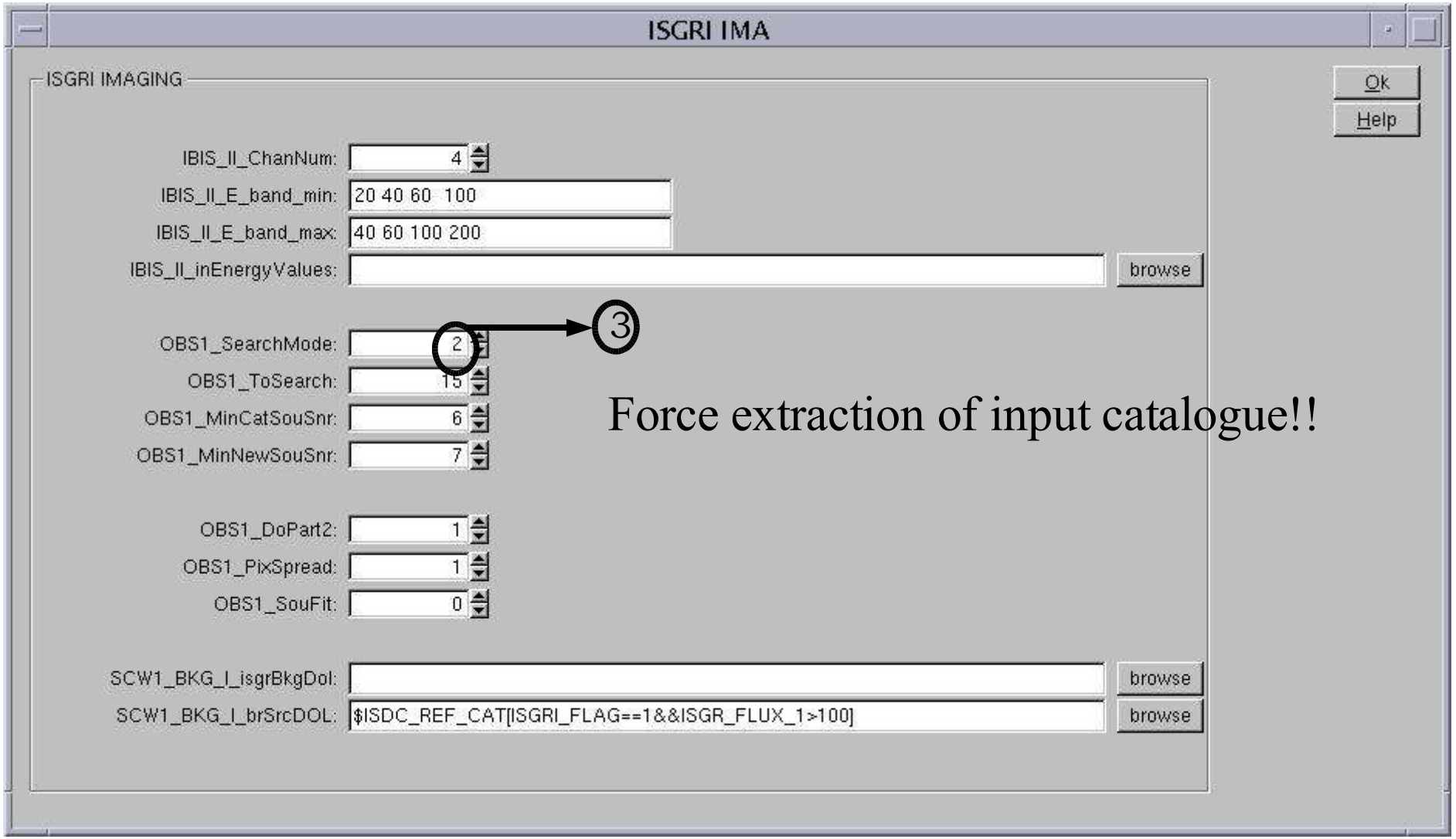
The NEW sources are ghosts (SearchMode=2)!!!!!
(this is on 18 scws)

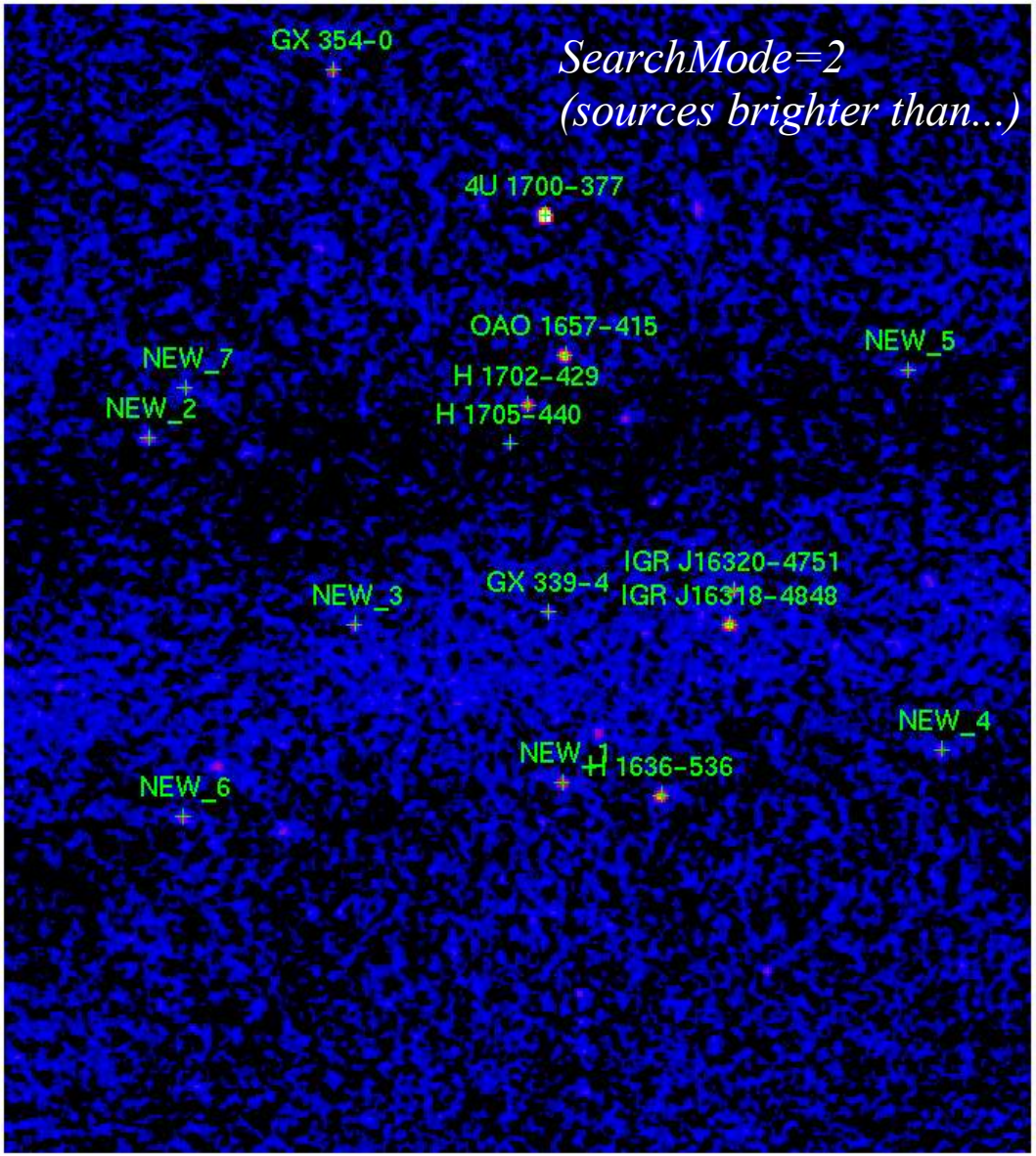
cd ../../

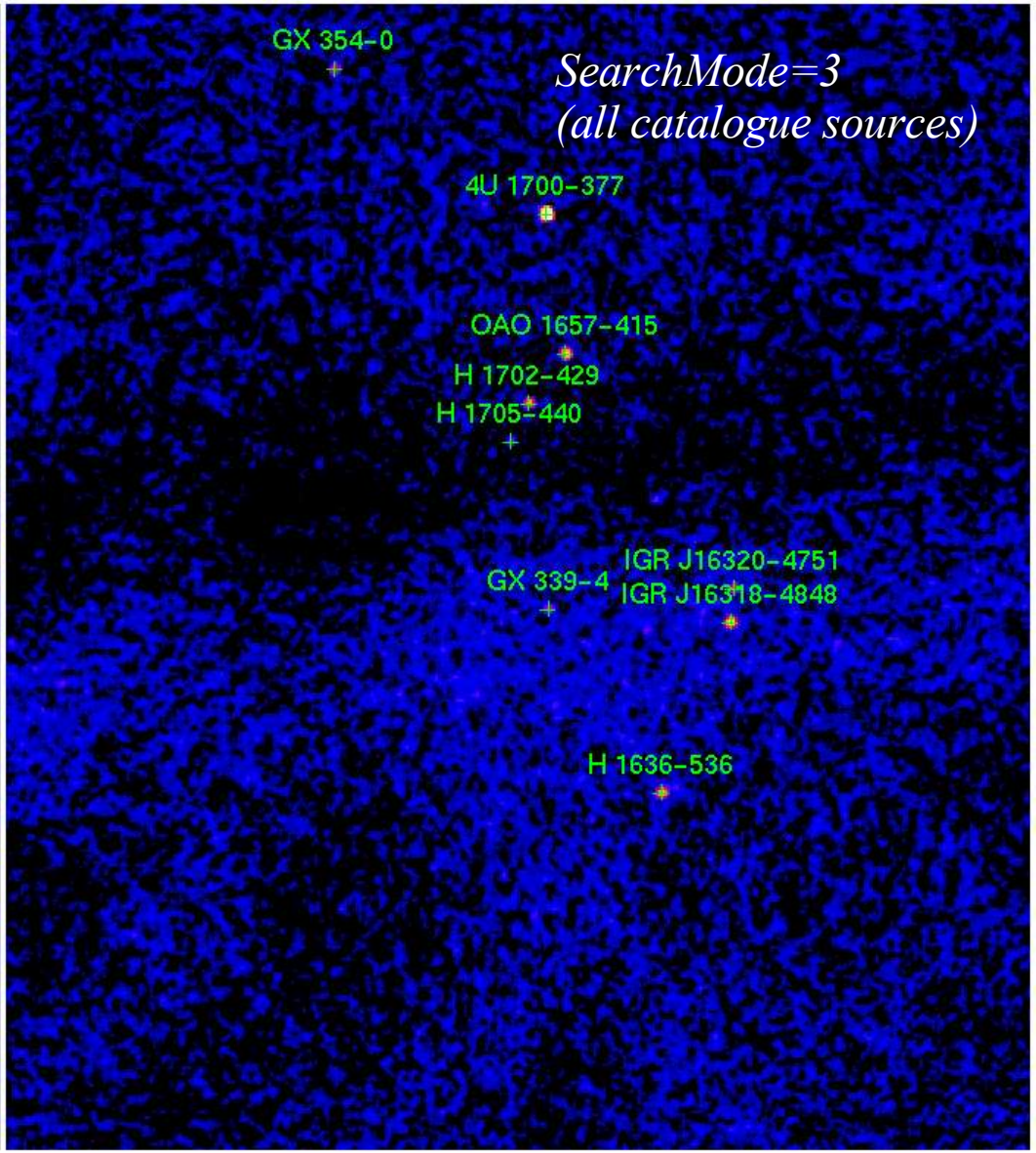
og_create idxSwg=rev49isgr ogid=rev49_isgri_mode3 baseDir="./" instrument=IBIS

cd obs/rev49_isgri_mode3

ibis_science_analysis




GX 354-0
SearchMode=2
(sources brighter than...)
4U 1700-377
OAO 1657-415
NEW_7
NEW_5
H 1702-429
NEW_2
H 1705-440
IGR J16320-4751
GX 339-4
NEW_3
IGR J16318-4848
NEW_4
NEW_1
H 1636-536
NEW_6


GX 354-0
SearchMode=3
(all catalogue sources)
4U 1700-377
OAO 1657-415
H 1702-429
H 1705-440
IGR J16320-4751
GX 339-4
IGR J16318-4848
H 1636-536

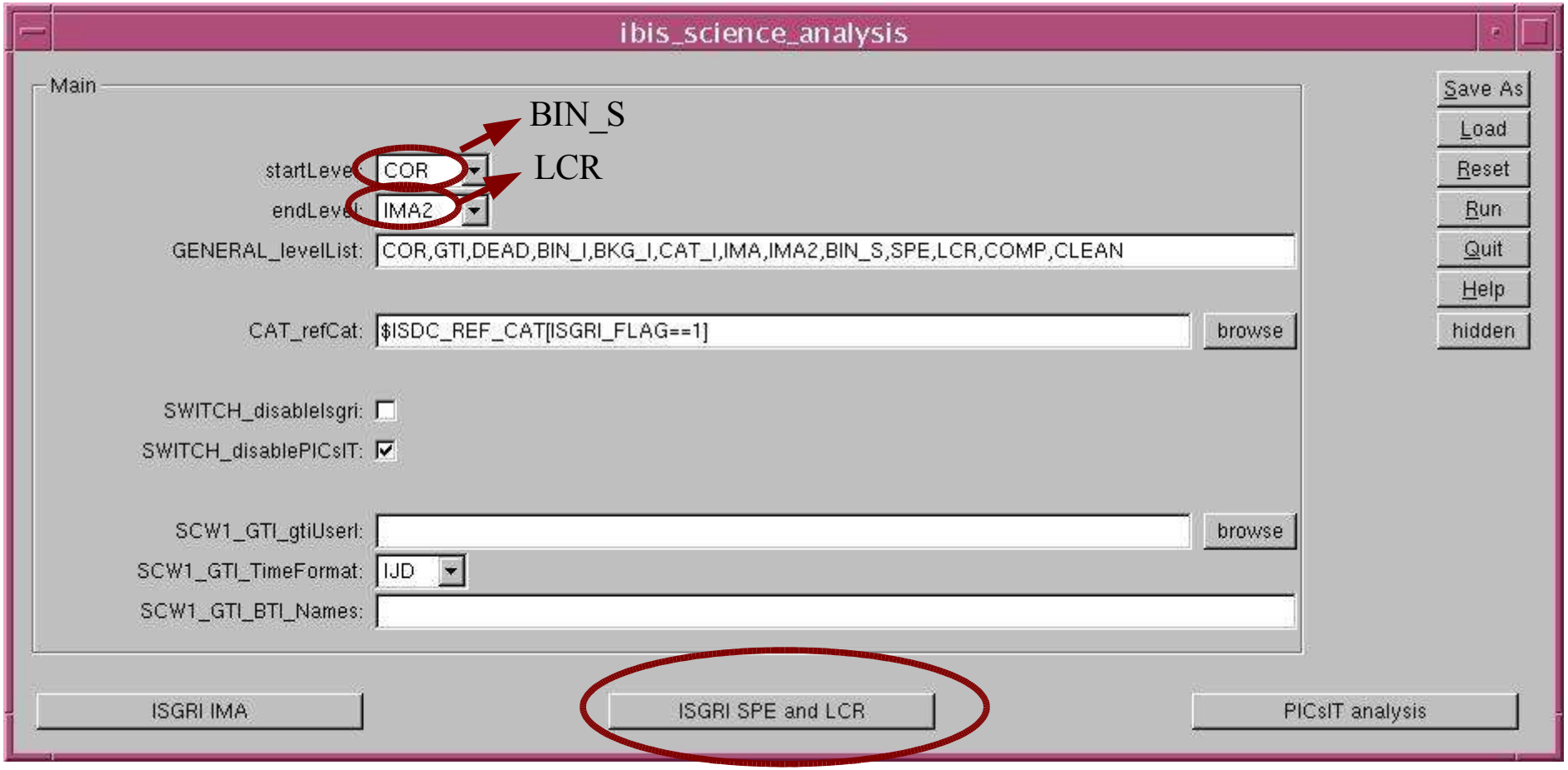
[C] EXTRACT SPE AND LCR

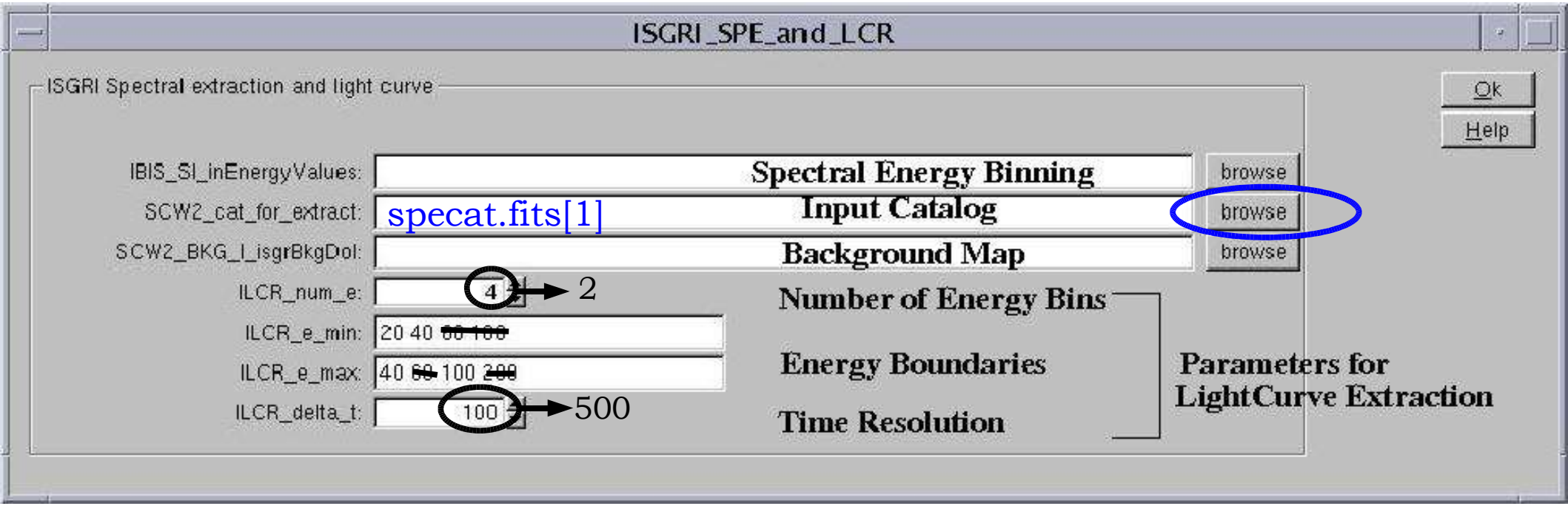
Coded mask: you need to extract SPE and LCR for all active sources

cp ***isgri_srcl_res.fits*** *specat.fits*

in specat.fits keep sources DETSIG> 6

ibis_science_analysis





Specat.fits is IMPORTANT!
Default is isgri_scrl_res.fits: long, useless and might fail!!
specat.fits: POSITION FROM FIT OR FROM CATALOGUE?

OK, Save and Run

Results:

• each pointing

obs/…/scw/004900320010.001/

isgri_spectrum.fits

isgri_lcr.fits

(and isgri_sky_res.fits from IMA)

Interested in all the results from GX 339-4?

How to collect the results:

src_collect	IMA
lc_pick	LCR
spe_pick	SPE

Aim of hands-on session: IMA and stop. Change catalogue and run SPE, LCR. Then collect!

What else?

Main options

- Prepare the data
  - User GTI
- Images
  - Do mosaic?
  - Fit source position?
  - Background removal
  - Spectrum from image?
- Spectra
  - Spectrum from fit position or catalogue one?
  - Energy binning
  - Background removal
  - Phase resolved spectroscopy
    - Hours to days: scw by scw
    - Seconds to hours: define user GTI
    - Below minutes: start from event list

- Lightcurves
  - up to about 60 sec binning: standard LCR
  - up to about 0.1 sec: *ii_light*
  - below 0.1 sec: start from event list

- No GUI!
  - You can run the analysis from command line

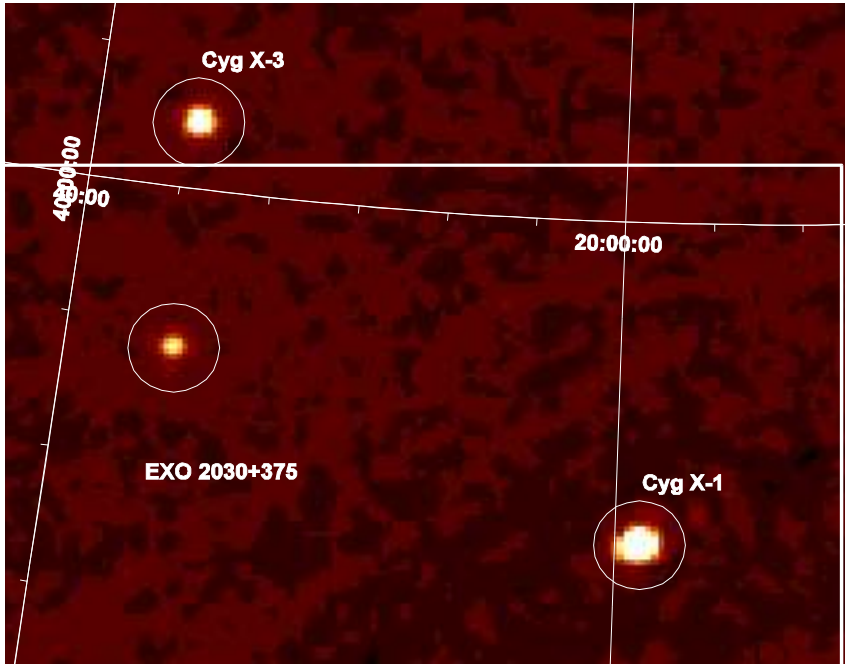
og_create idxSwg=SCW_IBIS.txt ogid=IBIS_3scw basedir="./" instrument=IBIS

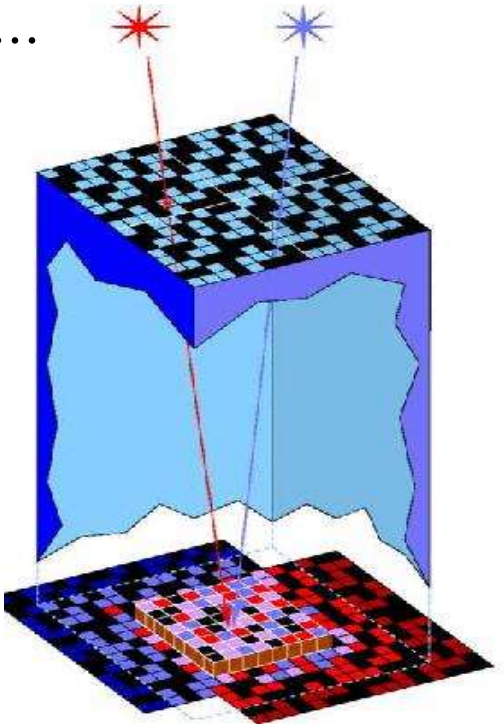
- Database?
  - Analyse science window by science window (15000 scws!)

Summary & Recommendations

ISGRI is a great instrument!!!!! but be careful…

Ghosts
new source?





Each source is background for the rest
you have to extract spectra for all the active sources in the FOV (specat.fits)

Read the Cookbook, Calibration report, Known issues, Scientific Validation on ISDC web pages.

References

Coded mask imaging:

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

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
- Goldwurm A., 2005, IBIS/ISGRI scientific validation report

IBIS analysis user manual, Cross-Calibration report, and other information:

- ISDC documentation

http://isdc.unige.ch/?Support+documents