



# PACS Spectroscopy pipeline and data products

Herschel DP Spectroscopy Workshop  
ESAC, Madrid, Spain  
24-25 March 2009

Speaker: Roland Vavrek (HSC)

Bart Vandenbussche, Jeroen de Jong, Jürgen Schreiber, Alessandra Contursi, Phil Appleton, Ekkehard Wieprecht, Eckhard Sturm, Katrina Exter, Beatriz Gonzalez

*and the PACS ICC*

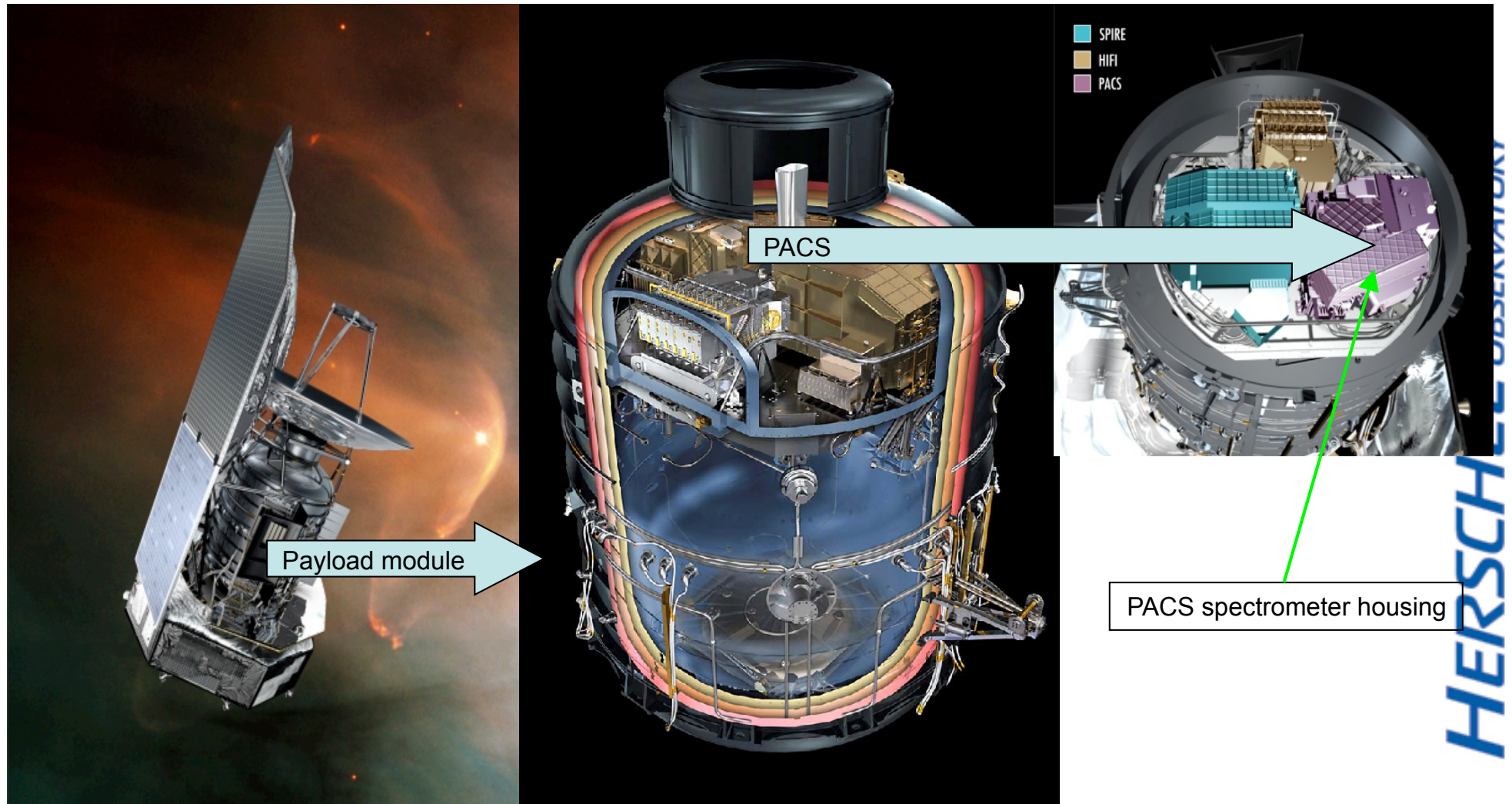


# Outline

- Instrument and AOT concept overview
- Pipeline, products and calibration concept summary
- Where to find documentation
- *Hands-on session: run the pipeline demo script together*

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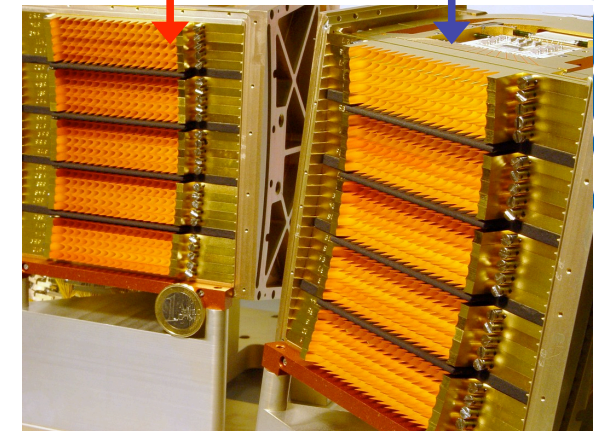
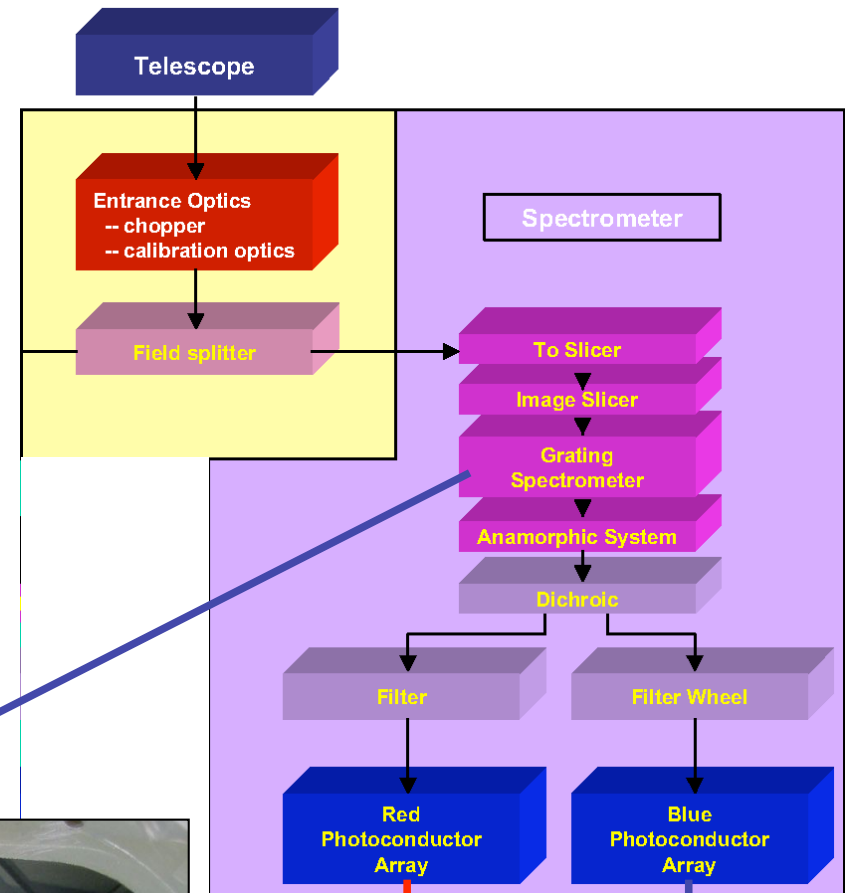
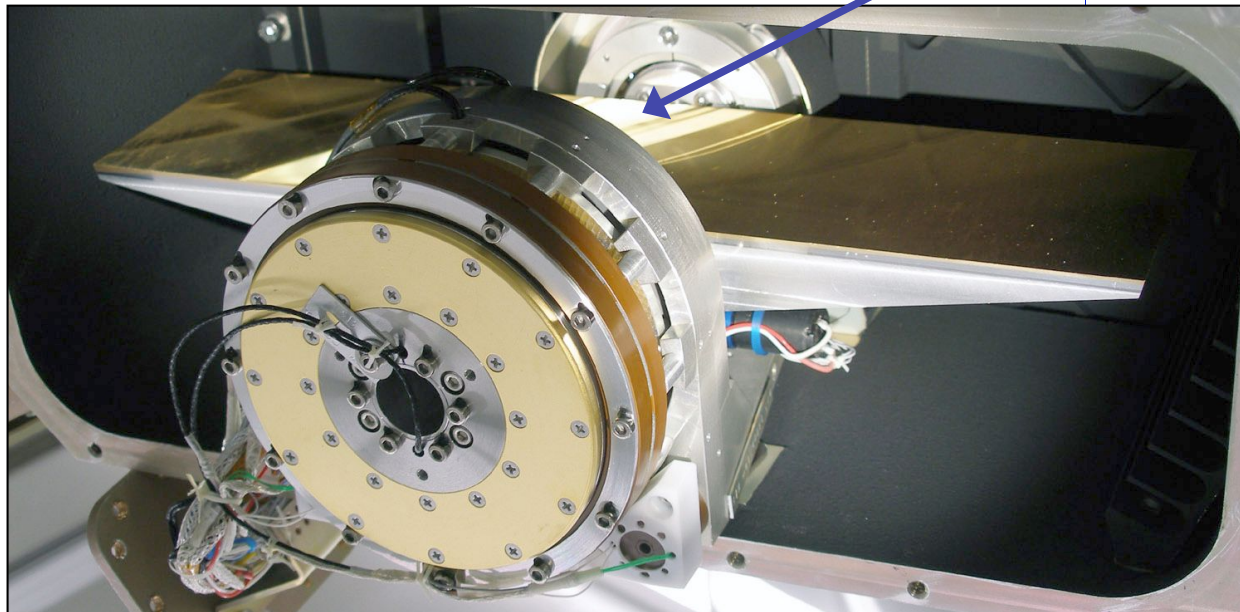
# PACS Spectrometer concept





# Diffraction grating spectrometer with high- and low-stressed Ge:Ga detector arrays

Grating: diffraction element used in 3 orders

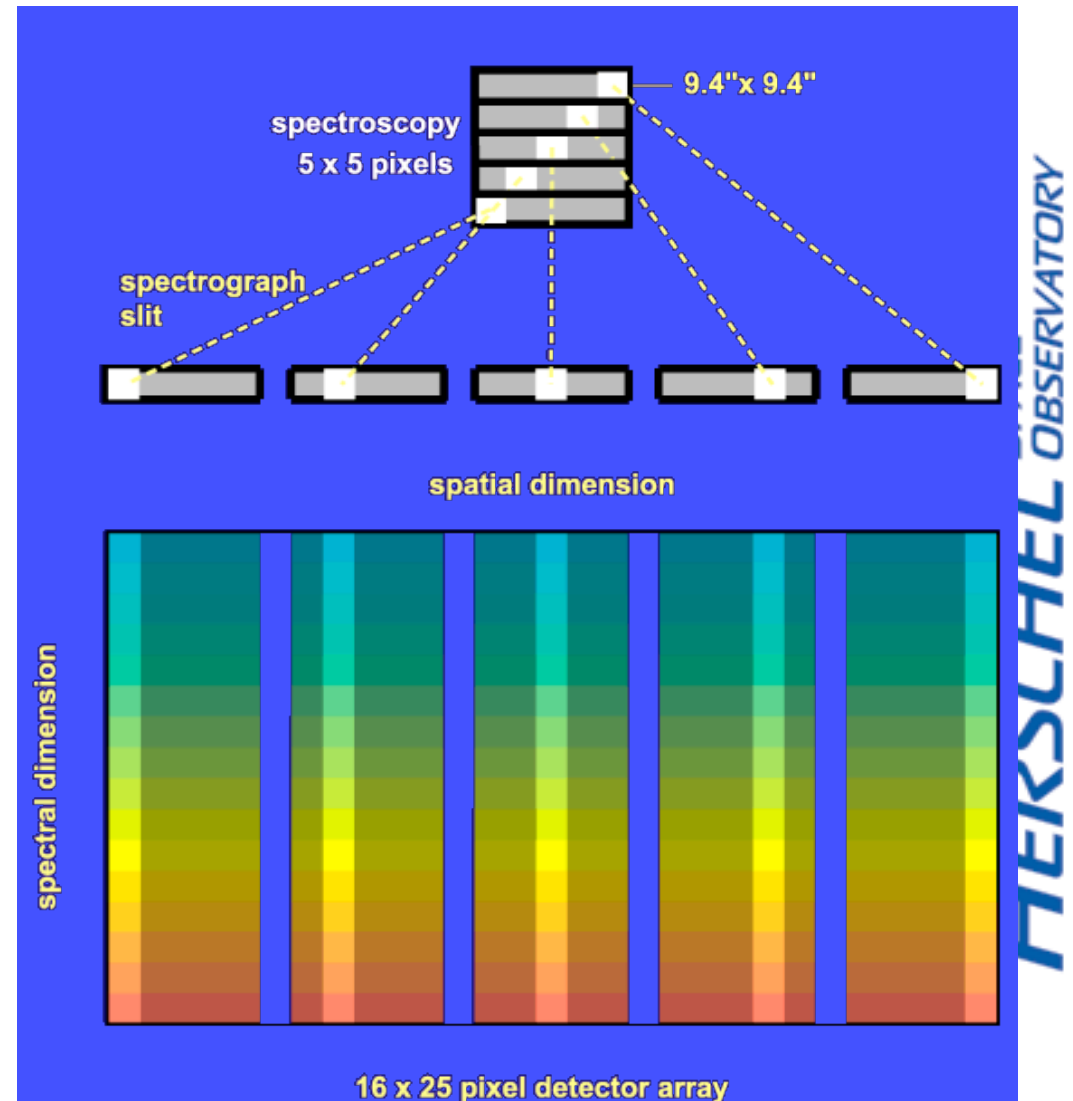




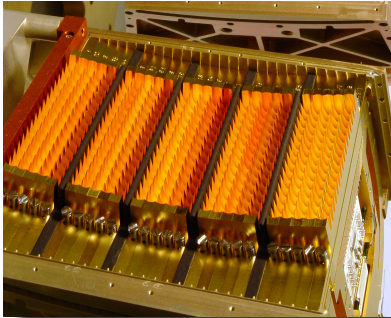
# Integral-field concept



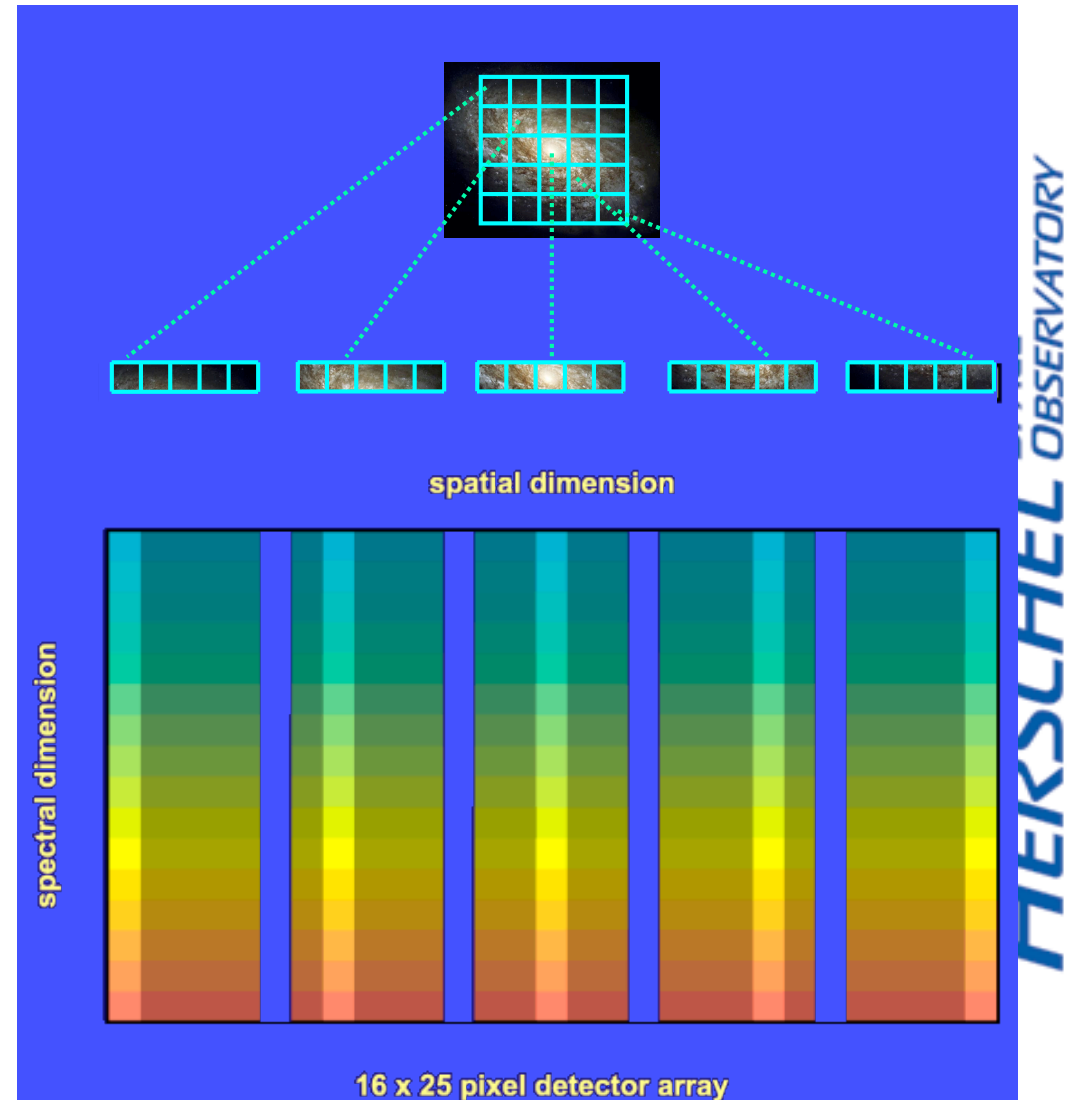
47"x47" (5x5 pixels) FOV  
rearranged via an image  
slicer on two 16x25  
detector arrays



# Integral-field concept



- Simultaneous 55-98 & 102-210  $\mu\text{m}$  spectroscopy
- Performance:
  - $\lambda/\Delta\lambda \sim 1500$
  - Sensitivity:  $\sim 5 \times 10^{-18} \text{ W/m}^2$  ( $5\sigma$ , 1h)



# PACS presents: Death of Photon



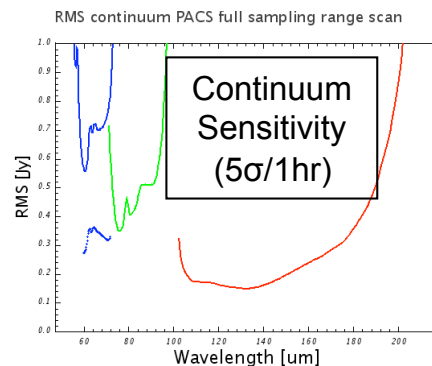
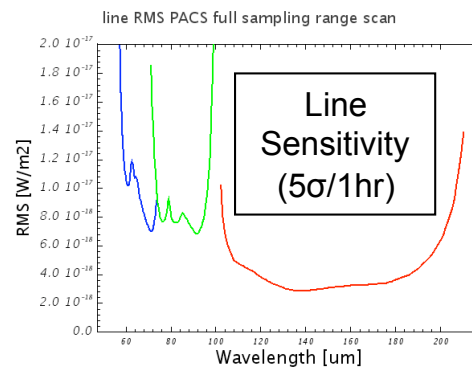
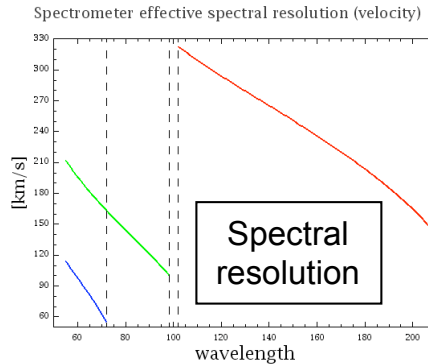
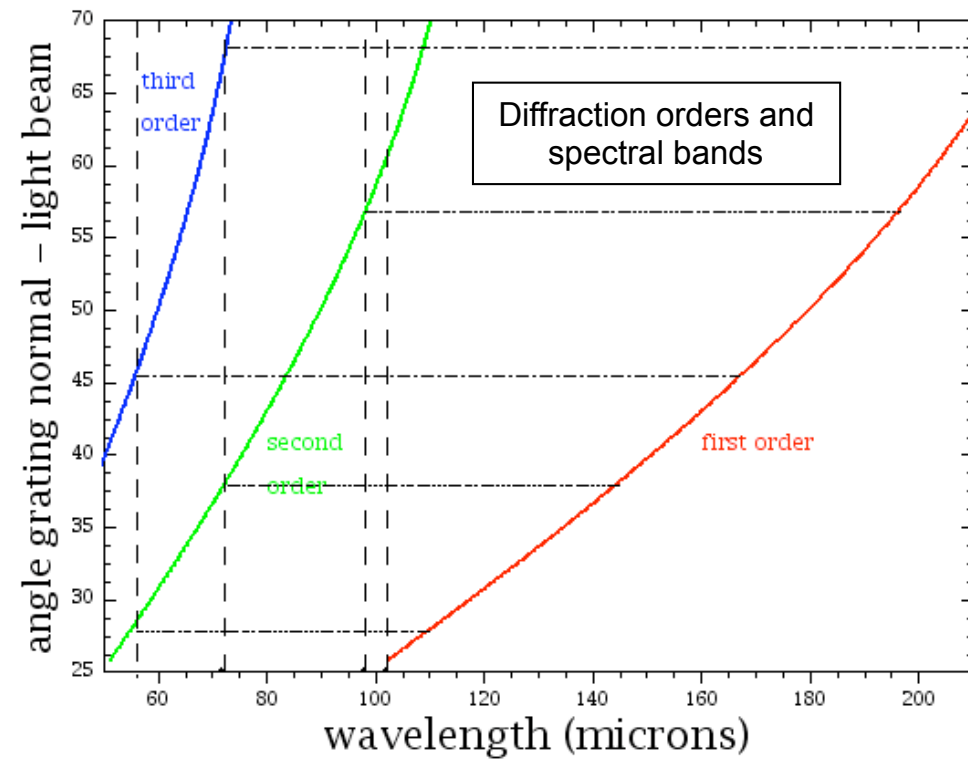
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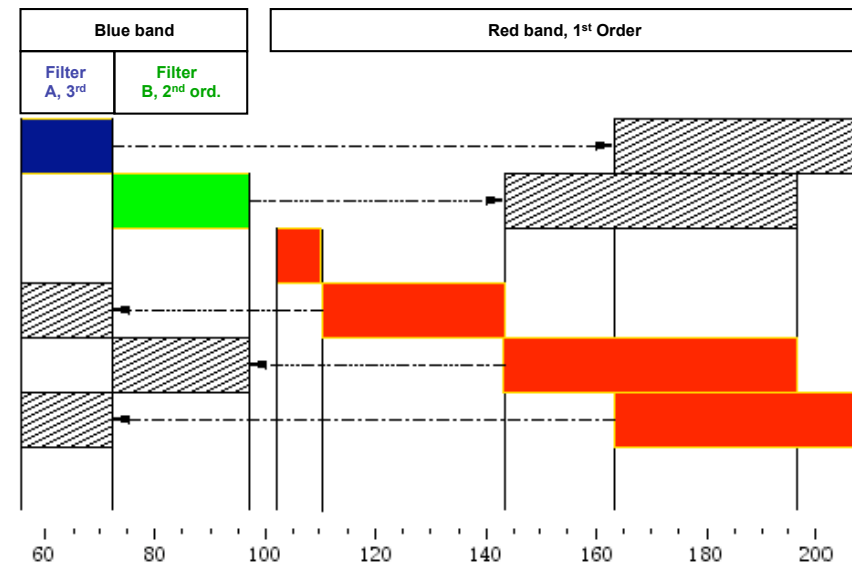
# PACS spectral bands



Grating angle – wavelength relation in Littow configuration



Nominal  
bands and  
parallel data



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# Spectrometer Astronomical Observing Templates (AOTs)

- **Line Spectroscopy AOT: observation of individual narrow lines:**

Signal modulation  
Techniques

- **Chopping/nodding**
  - Pointed, dithered and mapping modes
  - For isolated sources and rasters  $\leq 6$  arcmin
  - Variable grating sampling for faint and bright lines
- **Wavelength switching**
  - For mapping observations of crowded fields
  - Mandatory off-position

- **Range Spectroscopy AOT: observation of extended ranges, broad lines or continuum**

Range  
definition

- **Range scan** (same concept as Line Spectroscopy) *for broad lines*
- **SED** mode (1<sup>st</sup> and 2<sup>nd</sup> orders [71-98, 102-210  $\mu$ m] or 3<sup>rd</sup> order [55-73  $\mu$ m]) *for continuum*
- **SED blue sensitive** mode (extended 2<sup>nd</sup> order [60-73  $\mu$ m]) *for continuum*
- **Nyquist sampling** same as SED mode for restricted ranges *for continuum and bright lines*

Signal modulation  
Techniques

- **Chopping/nodding**
  - Pointed, dithered and mapping modes
  - For isolated sources and rasters  $\leq 6$  arcmin
  - For broad lines, multiple line coverage or continuum studies
- **Off-position**
  - For mapping observations of crowded fields

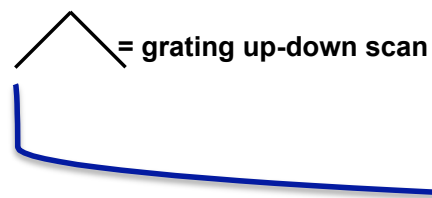
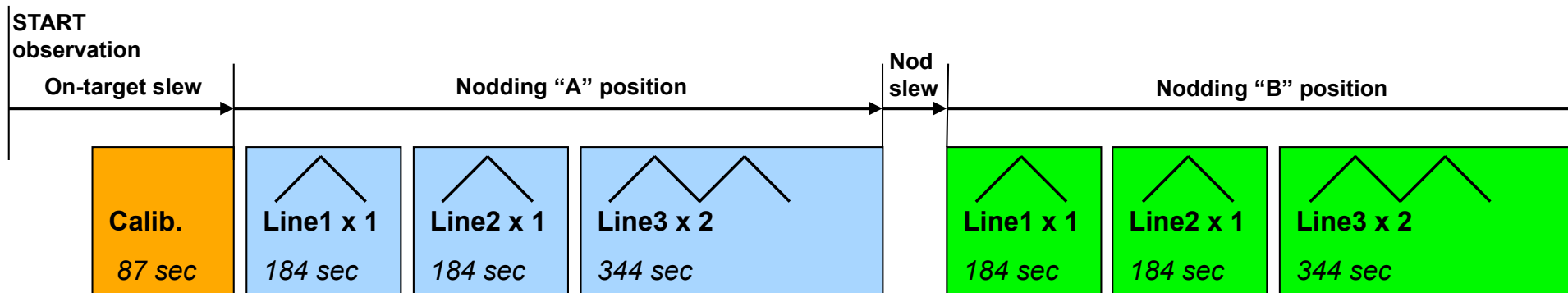


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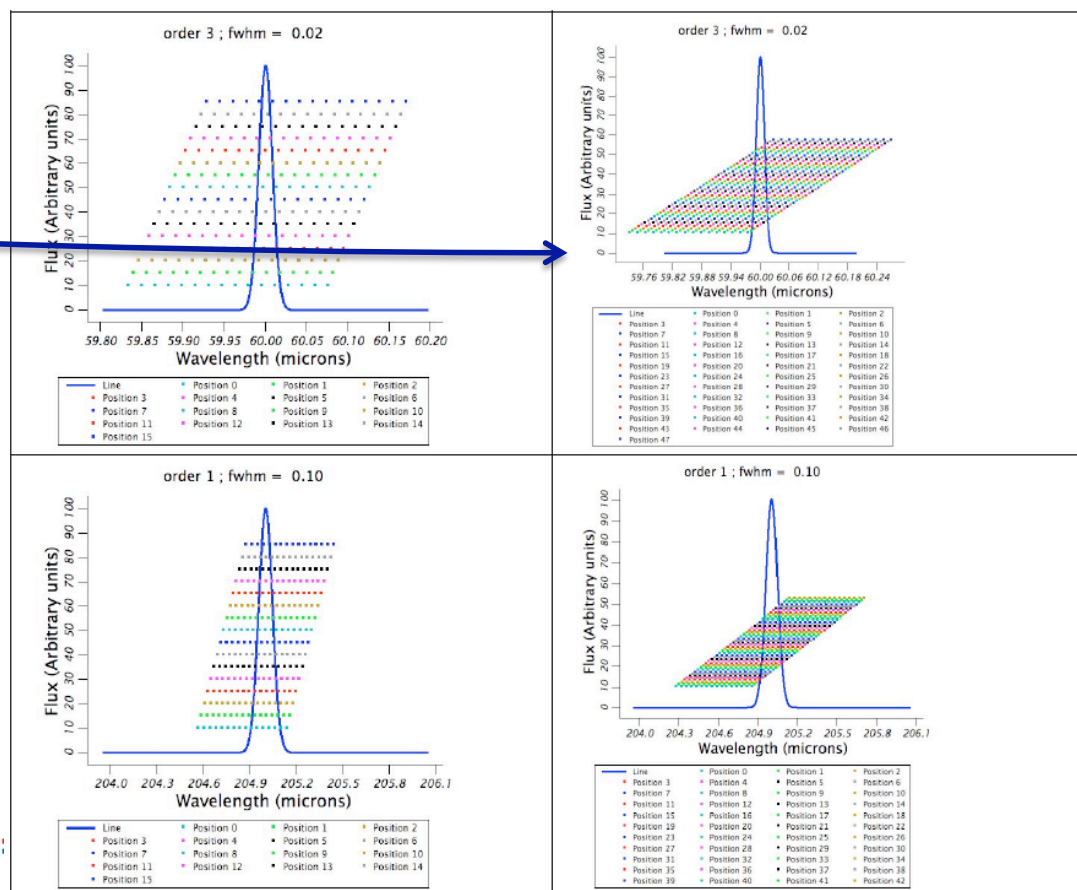




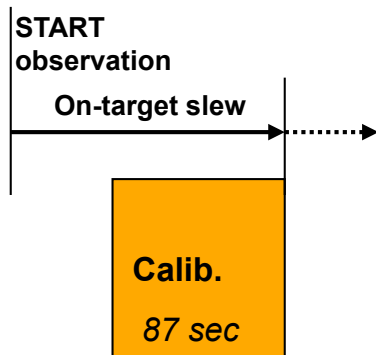
# Chop/nod AOT blocks



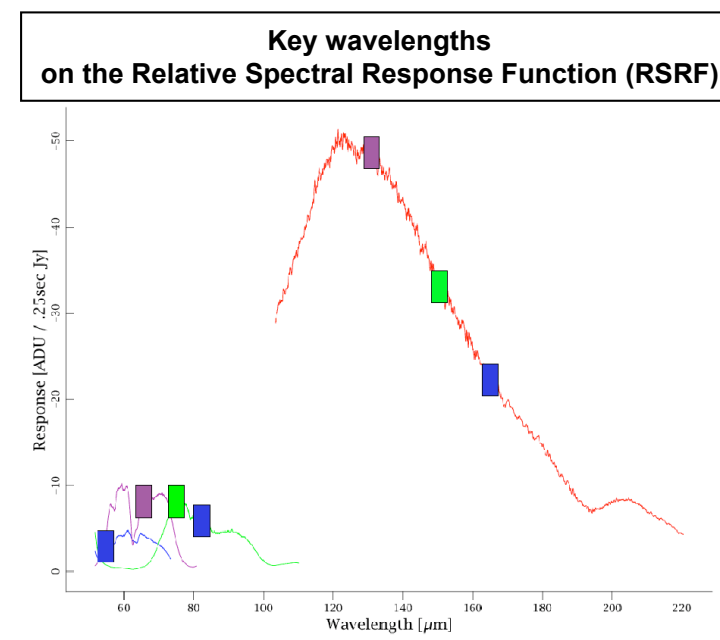
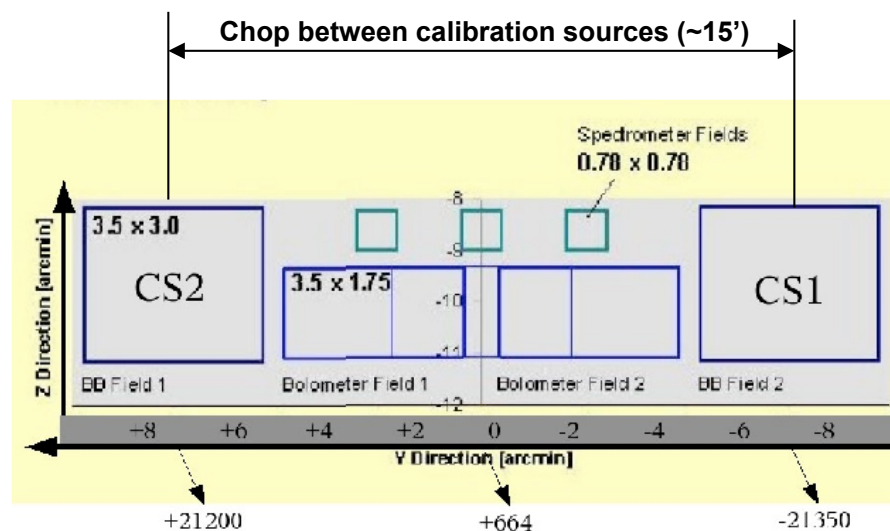
*Grating sampling in a single up-scan for bright line and high sampling modes*



# AOT calibration block



- On-target slew calibration block(s) on key wavelengths
- Calibrate the response on one point of the RSRF, we believe the RSRF does not change (a lot) over the mission lifetime
- Chopping between the calibration sources and grating up/down scans
- Homogeneous dataset over the entire mission lifetime
- One key wavelength per diffraction order:
  - flat part of the RSRF
  - close to the most frequently used lines



# ... and how blocks are defined in HSpot



## Nodding blocks

## Pointing blocks

PACS Line Editor

Unique AOR Label: PSpecL-0000

Target: NGC7027 Type: Fixed Single  
Position: 21h07m01.59s,+42d14m10.2s

Number of visible stars for the target: 23  
Star tracker target: Ra: 136.757 degrees Dec: -42.236 degrees

Wavelength Settings  
Selection of wavelength ranges  
Wavelength ranges [73-98] and [103-210] microns (2nd + 1st orders)

Line Id	Wavelength (μm)	Redshifted Wav.	Line Flux	Line Flux Unit	Continuum Flux	Line Width	Unit	Line Repetition
Line 1	97.00	97.00	0.00	10 <sup>-18</sup> W/m <sup>2</sup> /0.00	0.00	km/s		1
Line 2	80.00	80.00	0.00	10 <sup>-18</sup> W/m <sup>2</sup> /0.00	0.00	km/s		1
Line 3	158.000	158.00	0.00	10 <sup>-18</sup> W/m <sup>2</sup> /0.00	0.00	km/s		2

Observing Mode Settings  
Nodding/wavelength switching cycles  
Number of cycles: 2

Observing Mode Settings  
Choose one of the modes below:  
\* Chopping/nodding  
\* Chopping/nodding/bright line  
\* Wavelength switching

Observing mode parameters  
Chopper throw: Small, Medium, Large  
Chopper avoidance angle: Angle from degrees: 0.00, Angle to degrees: 0.00

Grid of pointing blocks showing 25 μm, ngc7027

PACS Range Editor

Unique AOR Label: PSpecR-0000

Target: ngc7027 Type: Fixed Single  
Position: 21h07m01.70s,+42d14m11.0s

Number of visible stars for the target: 23  
Star tracker target: Ra: 136.757 degrees Dec: -42.236 degrees

Wavelength Settings  
Range scan or SED mode  
Range mode [Range scan in [55-73] and [102-210] microns (3rd + 1st orders)]

Range ID	Blue Edge (μm)	Red Edge (μm)	Reference wav.	Line Flux	Line Flux Unit	Continuum Fl.	Line Width	Unit	Range Repetition
Range 1	55.00	73.00	55.00	0.00	10 <sup>-18</sup> W...	0.00	km/s		2
Range 2	102.00	210.00	210.00	0.00	10 <sup>-18</sup> W...	0.00	km/s		1

Observing Mode Settings  
Nodding or map repetition cycles  
Repetition: 1

Depth of the observation is set via repetition factors:

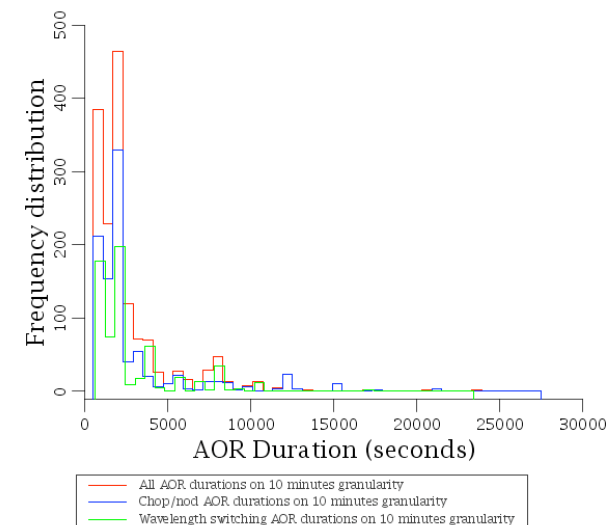
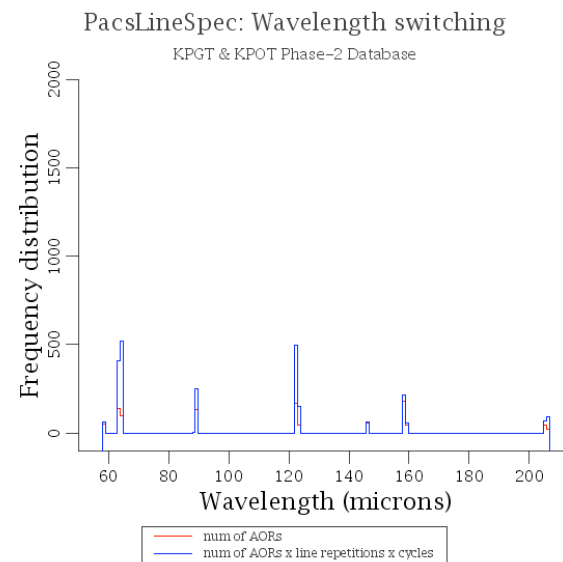
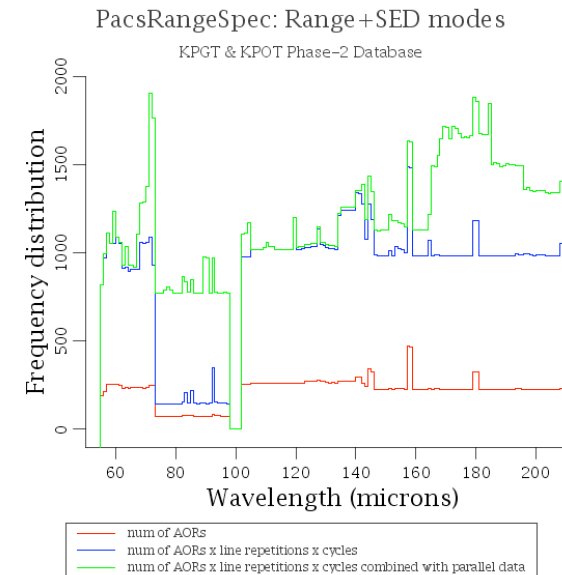
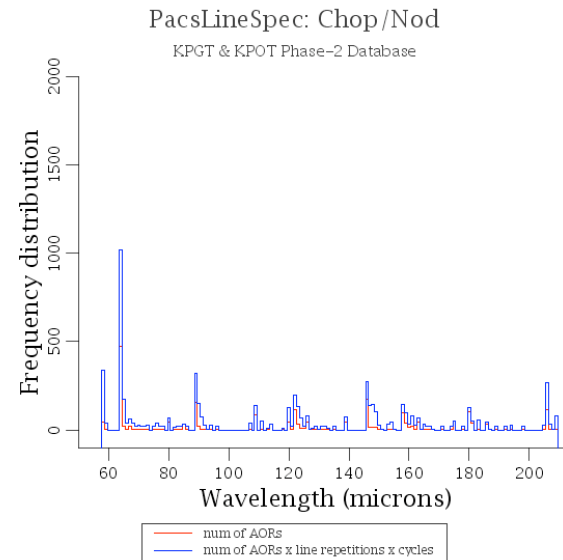
- Line/Range repetition for relative Line/Range strength, total number of repetitions is  $\leq 10$  to limit the maximum block duration
- Single repetition in SED mode block
- Nodding/switching/mapping cycles define how many times a block has to be repeated
- Overlap between pointing blocks (d1, d2 step size < 47")

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# Spectroscopy observing modes

## *Key Programmes statistics*



# Pipeline and products



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# Pipeline concept



- ✱ Keep pipelines independent of AORs as much as possible
- ✱ Natural definition of products at different processing levels
- ✱ Take fully advantage of interactive system:
  - ✱ *Each pipeline branch corresponds to a set of tasks, that can be executed step by step.*
  - ✱ *Users can inspect data at any time using plotting and displays tools available in the DP system*





# Data Structure (Obs. Context)



## o Level-0

- + instrument detector readout timeline
- + instrument housekeeping
- + other instrument-specific data

## o Auxiliary

- + Pointing
- + Orbit
- + spacecraft housekeeping
- + ...

## o Level-1

- + All instrument effects taken out

## o Level-2

- + Rebinned, publishable products

## o Calibration

- + Calibration products used to process level-1 and level-2 delivered by the HSA

# PACS raw signal



- ✱ PACS detectors are Photoconductors
- ✱ Infalling photons change photoconductor resistance
- ✱ Photocurrent is integrated on a capacitance in the read-out circuit: generation of ramps (64 readouts)
- ✱ Increase of Voltage over the capacitance measures infalling photons. This changes ramp's slope (signal)
- ✱ Data rate limit: we have to average 8 read-outs on board (over 64 ro). So “raw” signals (i.e. Level 0 products) to astronomers are ramps with sub-means





# Pipeline input data

## Level 0 Products

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# Raw telemetry

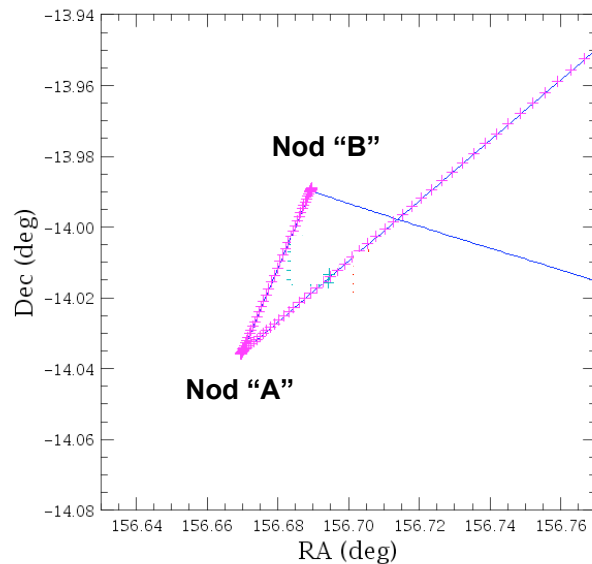
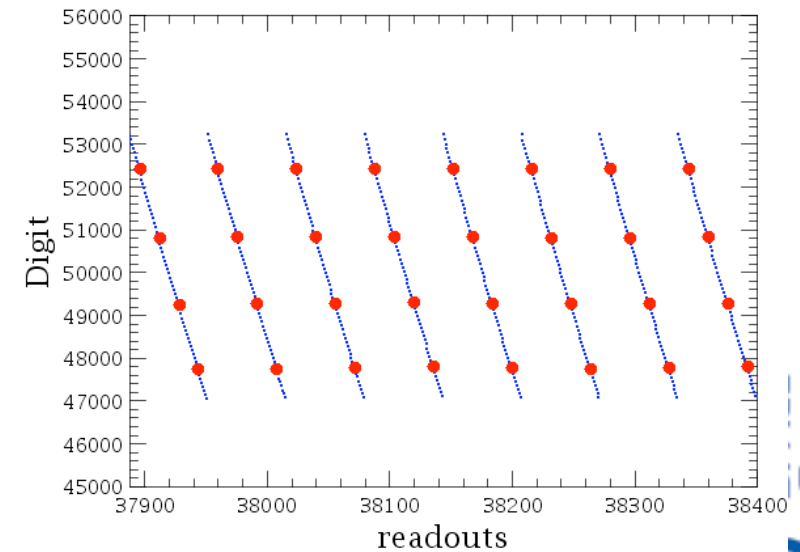
- Science data
- Housekeeping
- Pointing

on-board averaged data →

e.g. mechanism positions

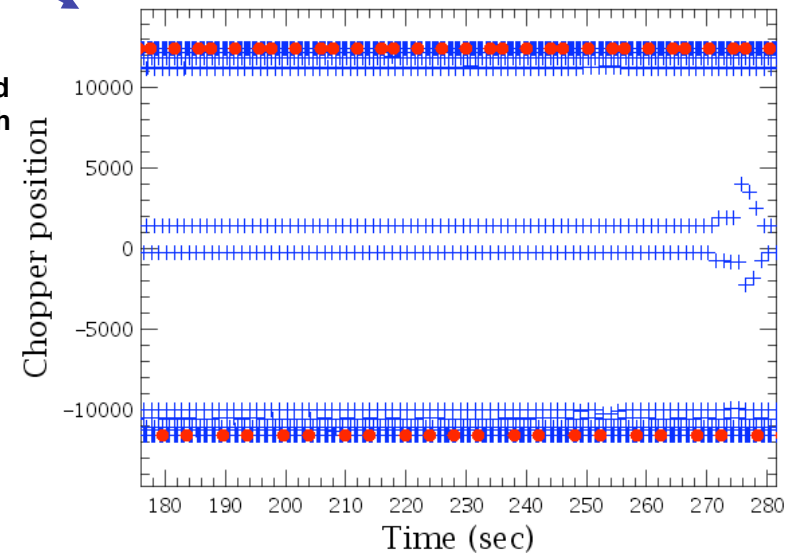
Telescope boresight attitude info

SOVT1 OBSID=3221226011

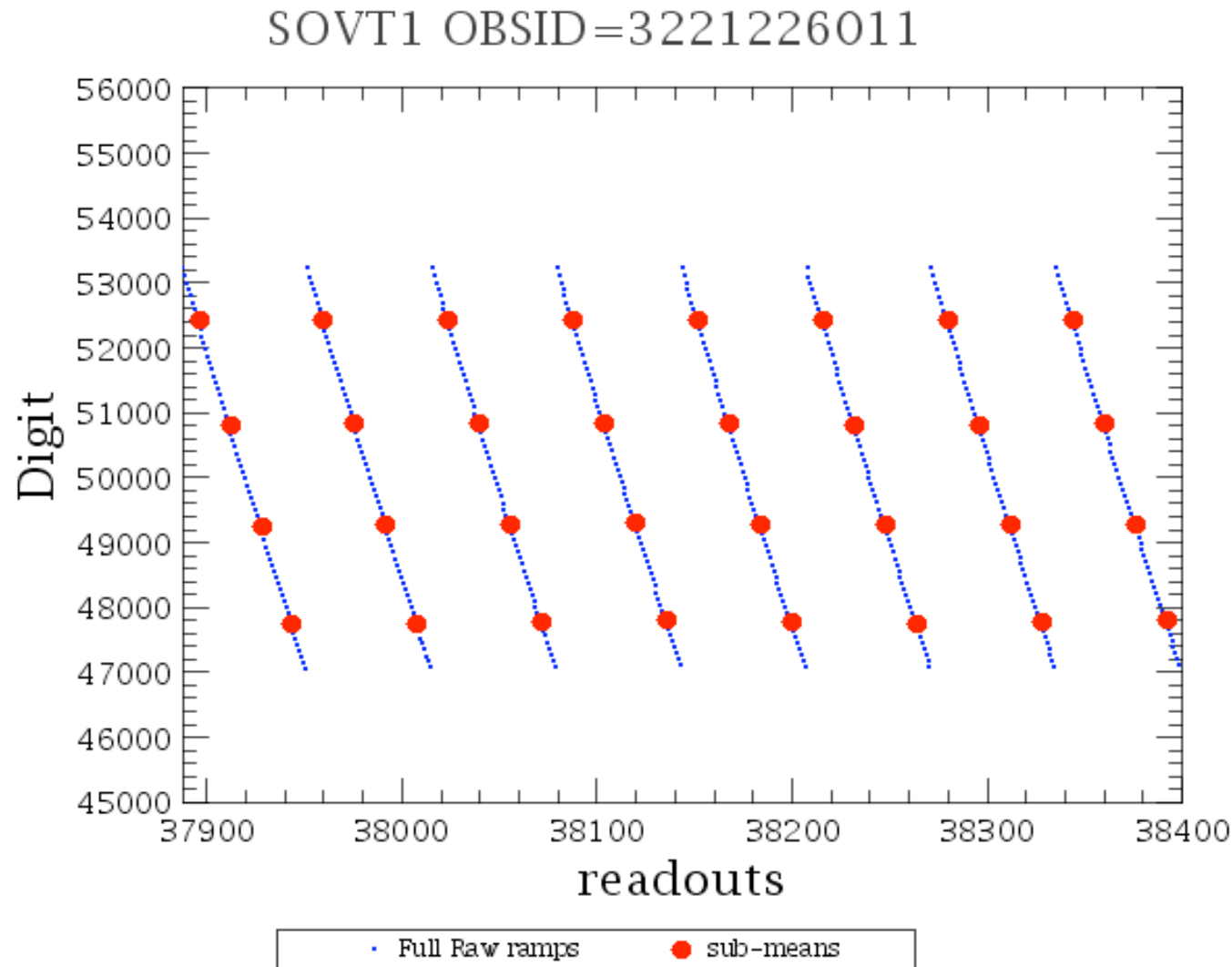


Some of the HK data essential for data reduction are associated with science data at high time resolution e.g.:

- Chopper position
- Grating position
- Filter wheel position
- AOT block ID
- ...

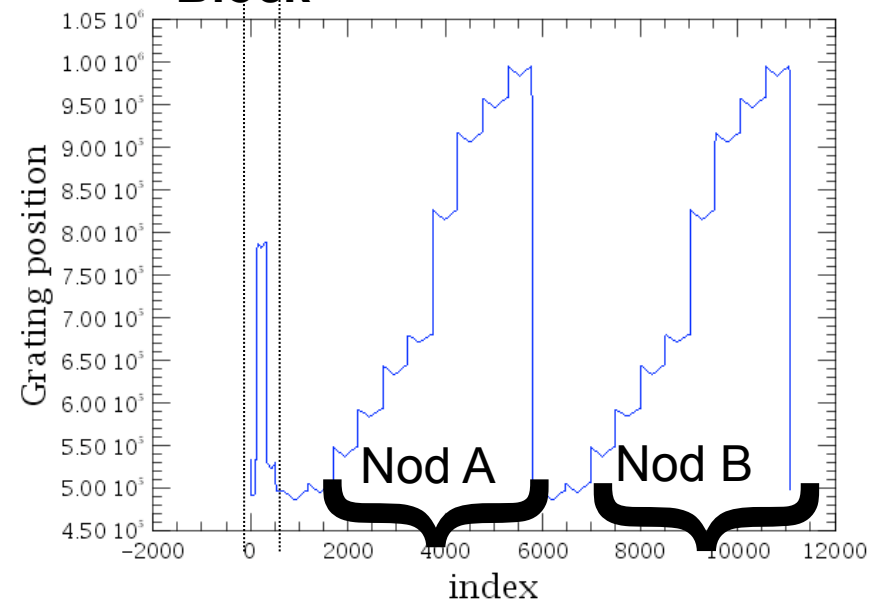
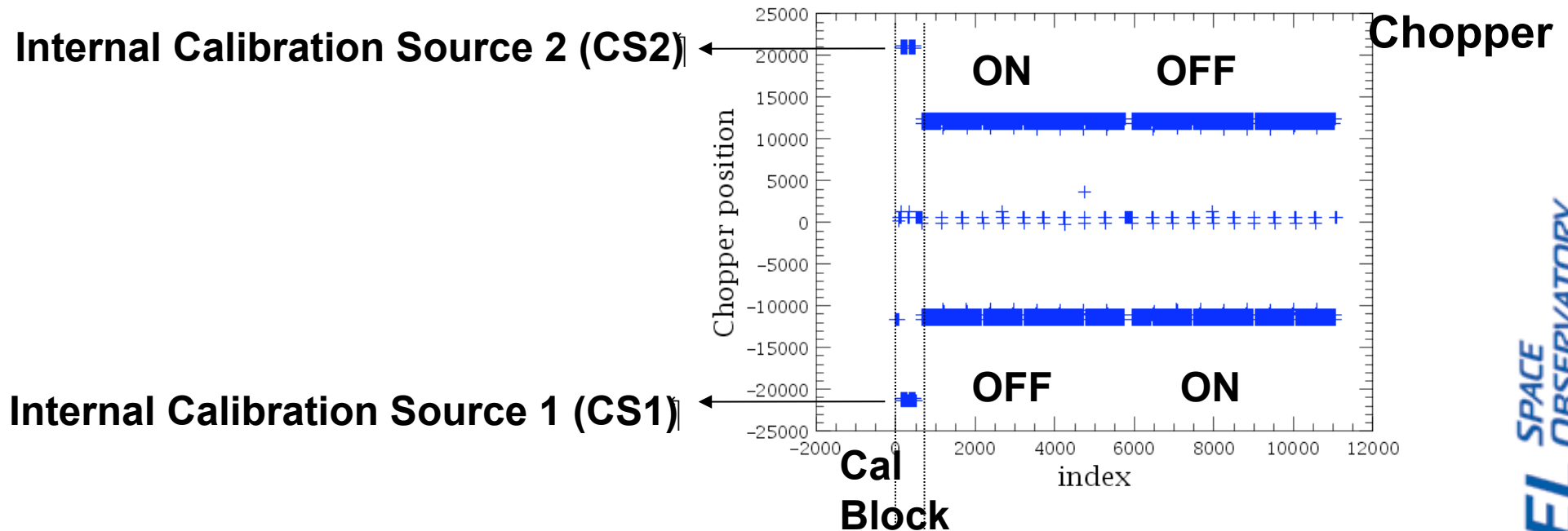


# Raw data: ramps with sub-means



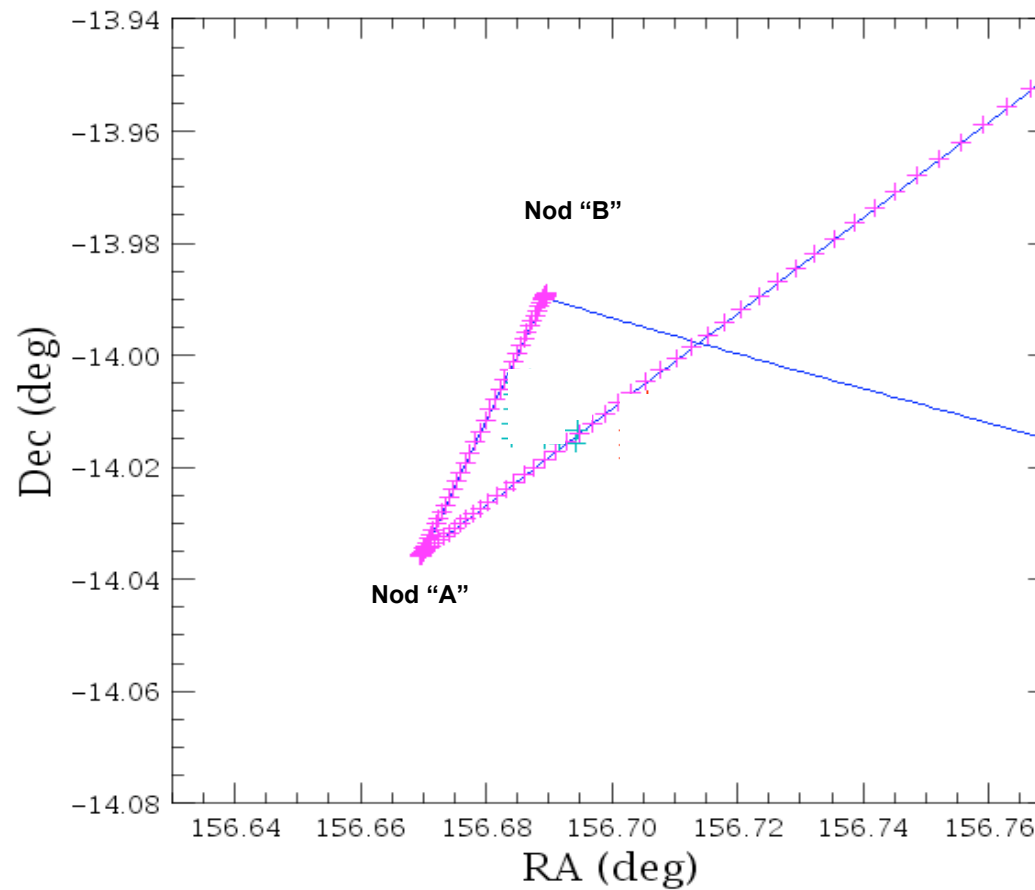


# Mechanisms

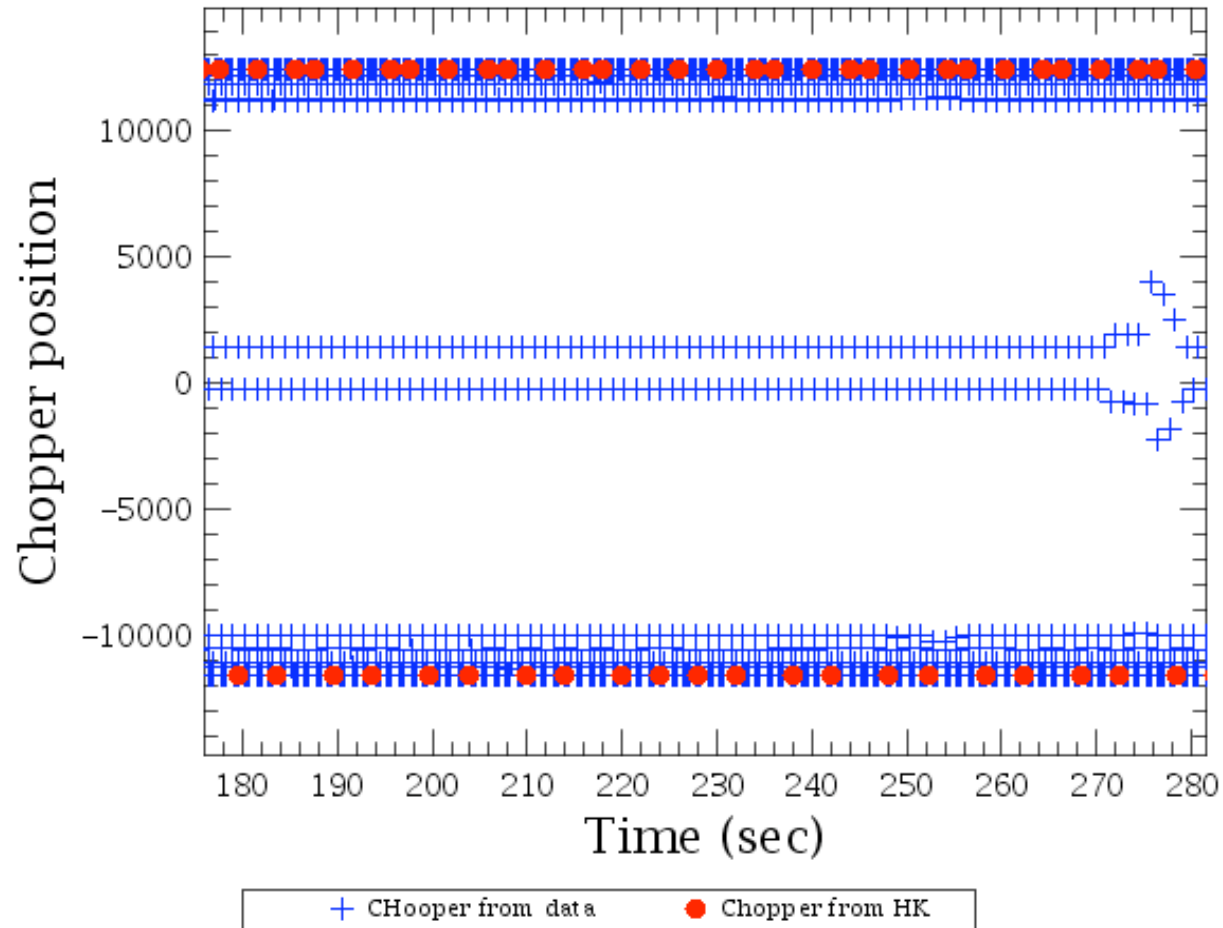


# Pointing

Telescope boresight  
attitude info



# Housekeeping



Some of the HK data essential for data reduction are associated with science data at high time resolution e.g.:

- Chopper position
- Grating position
- Filter wheel position
- AOT block ID
- ...

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# Color scheme for pipeline block diagrams



***Data products  
in/out***

***Pipeline step not yet  
completed***

***Pipeline step  
completed***

***Pipeline step  
not yet coded***

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# From Level 0 to 0.5

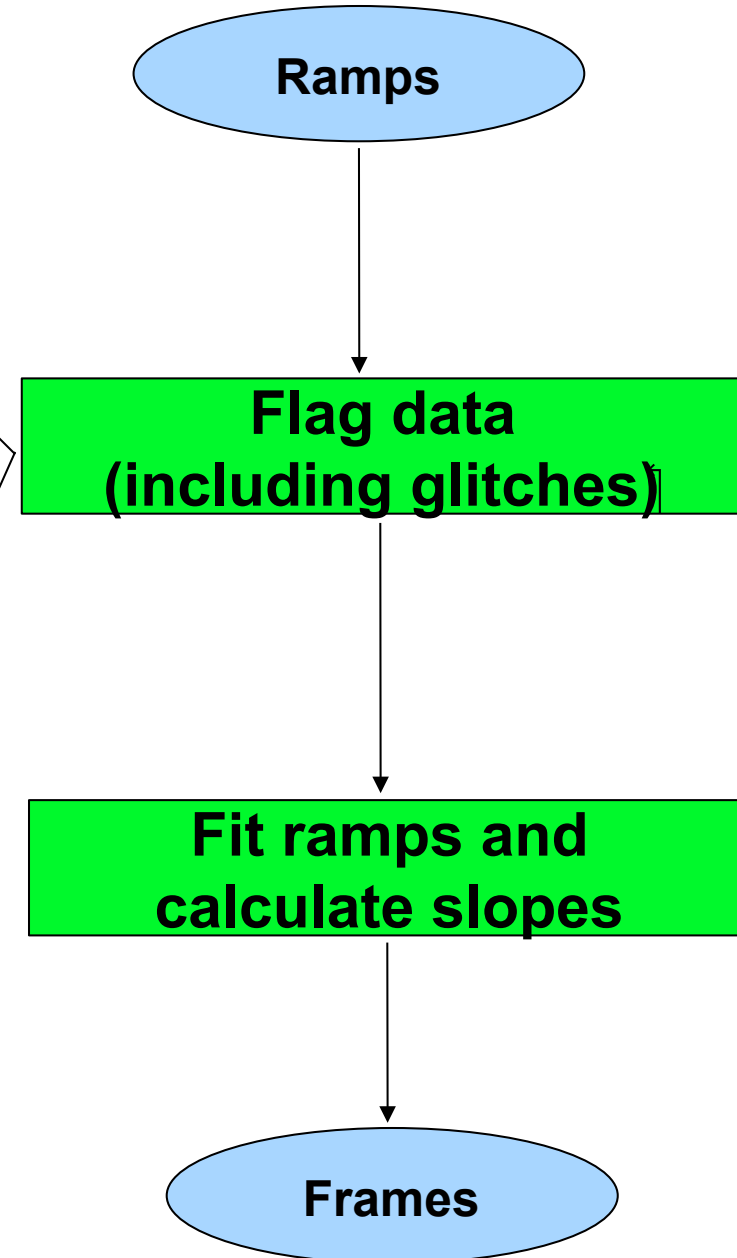
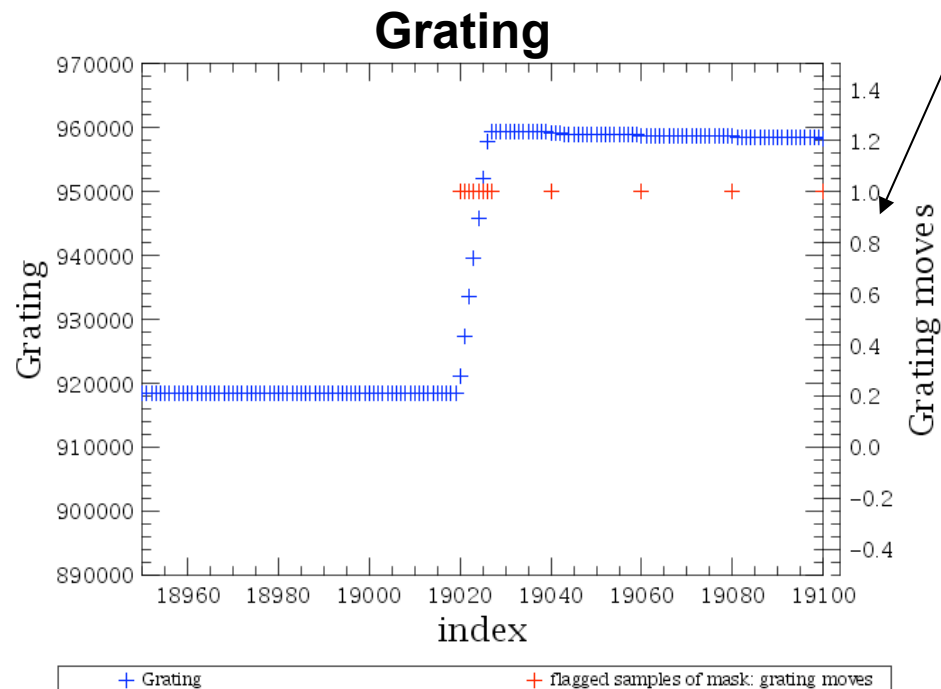
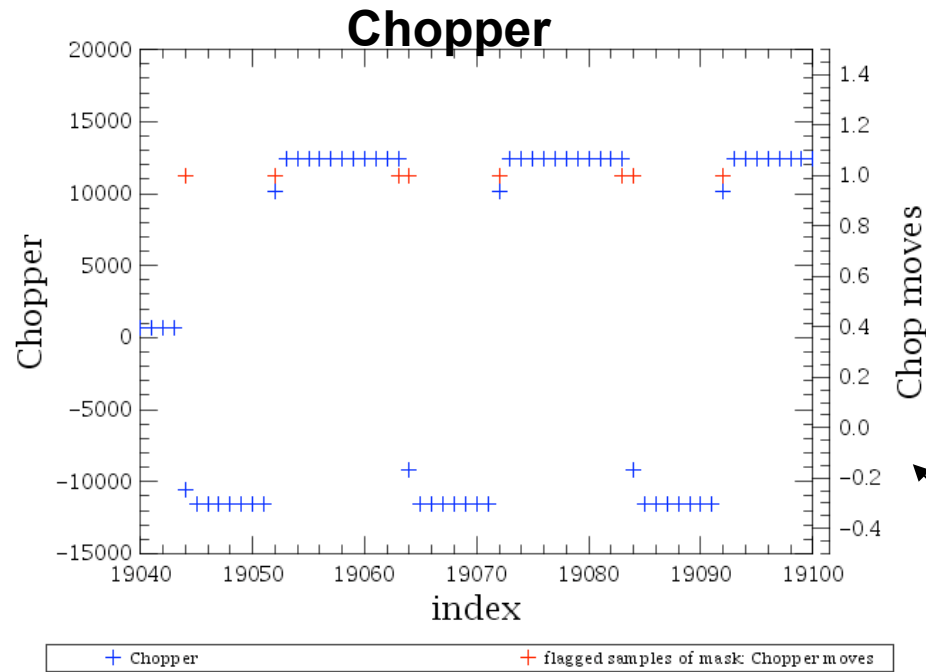
## ***AOR independent***

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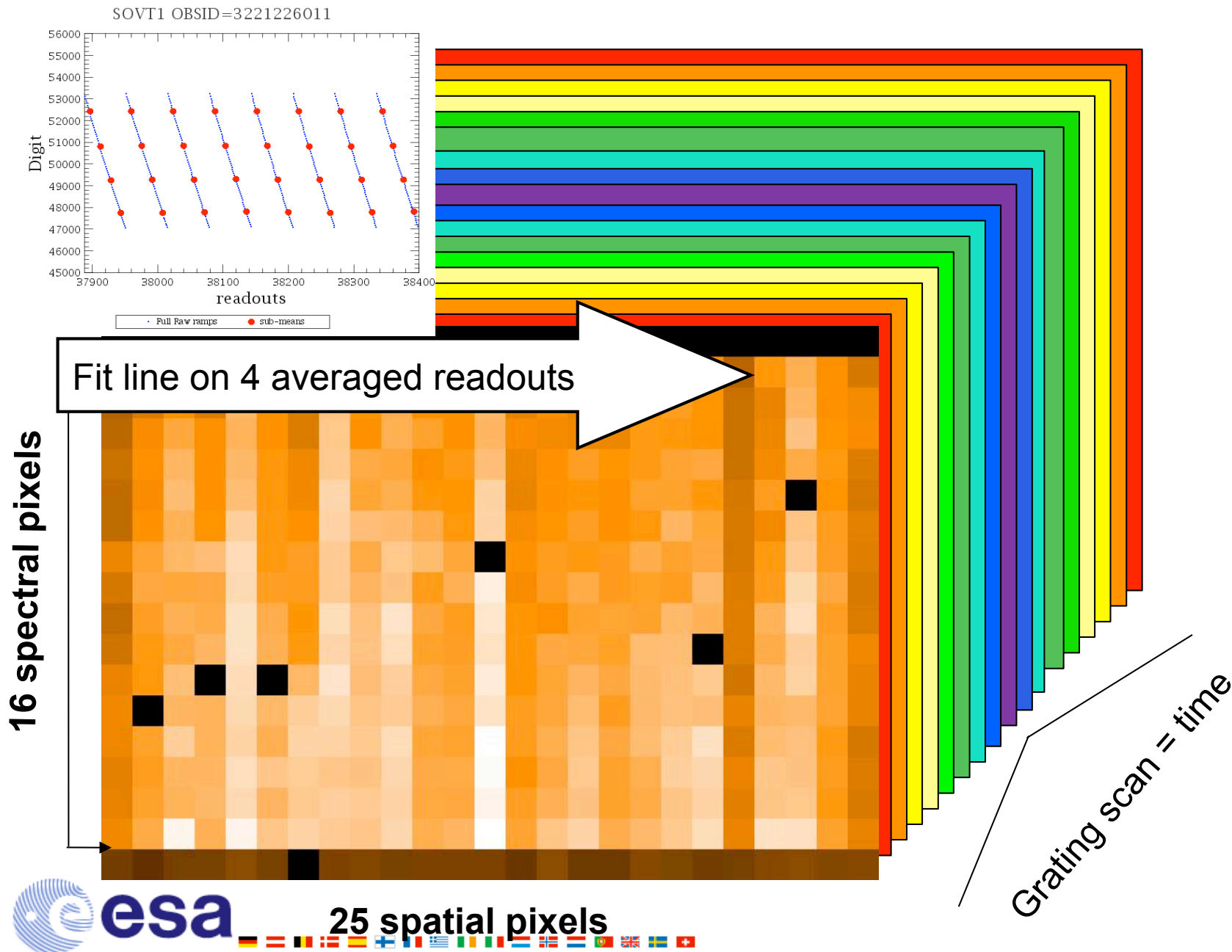


# LEVEL 0



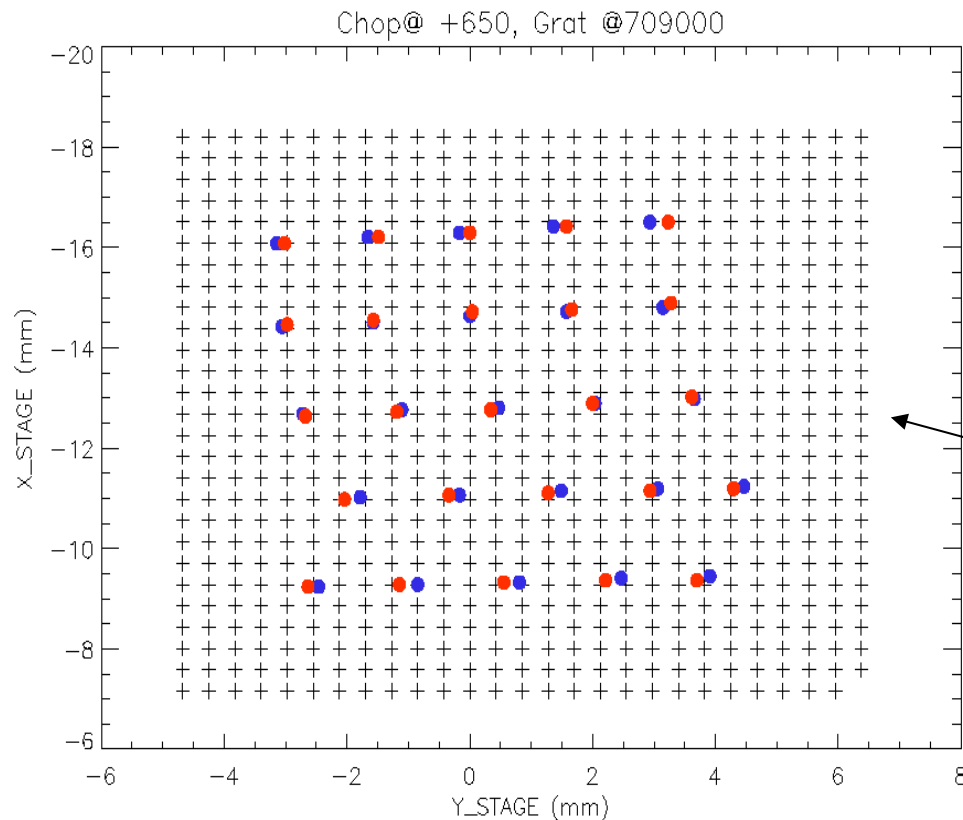
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# What do frames look like?



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# 5x5 FOV



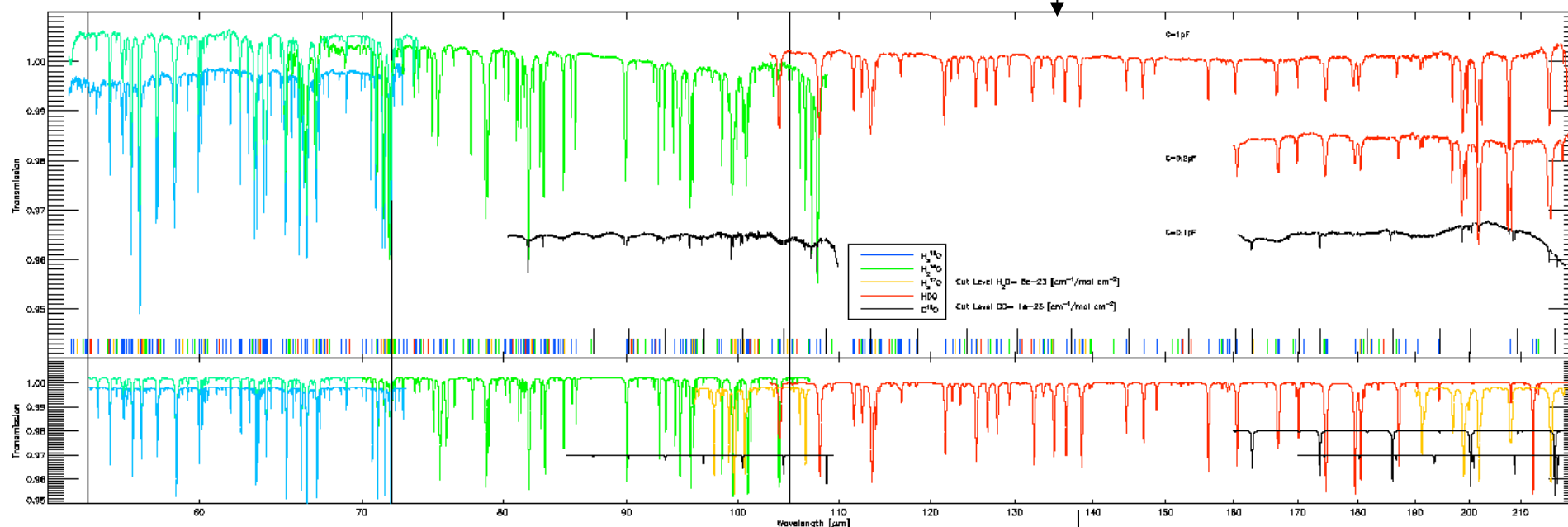
**Assign Ra-Dec to central pixel  
reading the Herschel pointing  
and assign coordinates to all  
other pixels from spatial distortion  
calibration files**

Frames

Identify logic blocks  
(nods, lines, etc..)

Add pointing and assign  
Ra and Dec

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Assign wavelength to each pixel.  
Polynomial fit based on water cell  
wavelength spectrum observed  
in ground tests

Wave calib

Correct non-linearity due  
to cryo electronics

Derived from ground tests



Not sure these will be necessary



Non linearity with flux

Transient  
(sources and glitches)

Difference of the Internal  
Cal Sources signals

Dark

Response at time  
Cal block ( $t_{cs}$ )  
(Flat Field, Jy/V/s)

Cal blocks

Frames



Level 0.5

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From Level 0.5 to 1

***AOR dependent !***

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# Flux calibration concept for chopped obs.



- ★ Difference of Internal Cal Sources signals gives Dark(pix,t) and  $R(\text{pix}, t_{cs})$

- ★ On-Off difference of the data nodes A and B is:

$$\Delta^A(\text{pix}, \lambda) = (S_{\text{Source}} + S_{\text{Tel}+} - S_{\text{Tel}-}) * \text{RSRF}(\text{pix}, \lambda) * R(\text{pix}, t)$$

$$\Delta^B(\text{pix}, \lambda) = (S_{\text{Source}} + S_{\text{Tel}-} - S_{\text{Tel}+}) * \text{RSRF}(\text{pix}, \lambda) * R(\text{pix}, t)$$

- ★  $R(\text{pix}, t) \neq R(\text{pix}, t_{cs})$  due to glitches

Known from  
ground tests

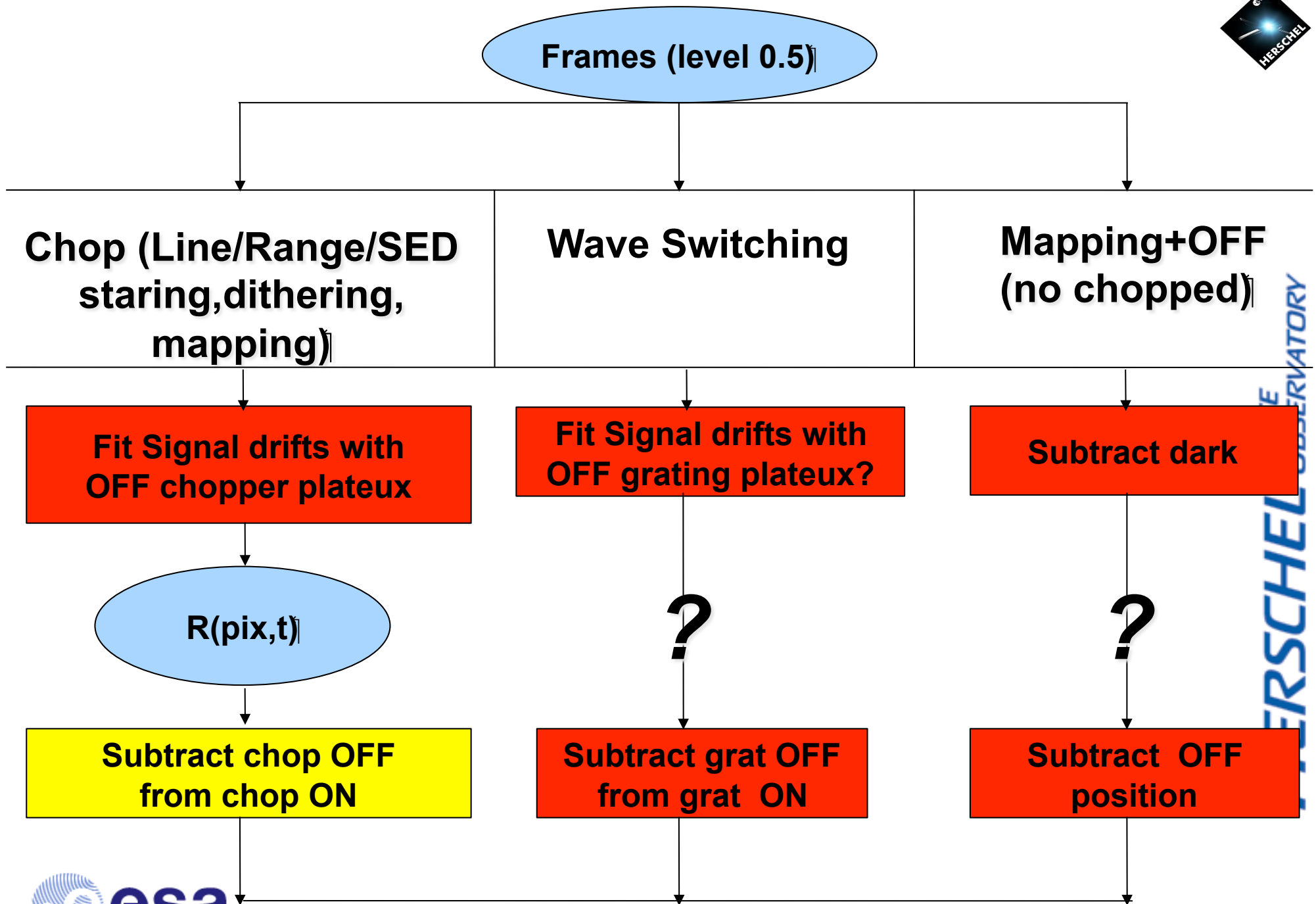


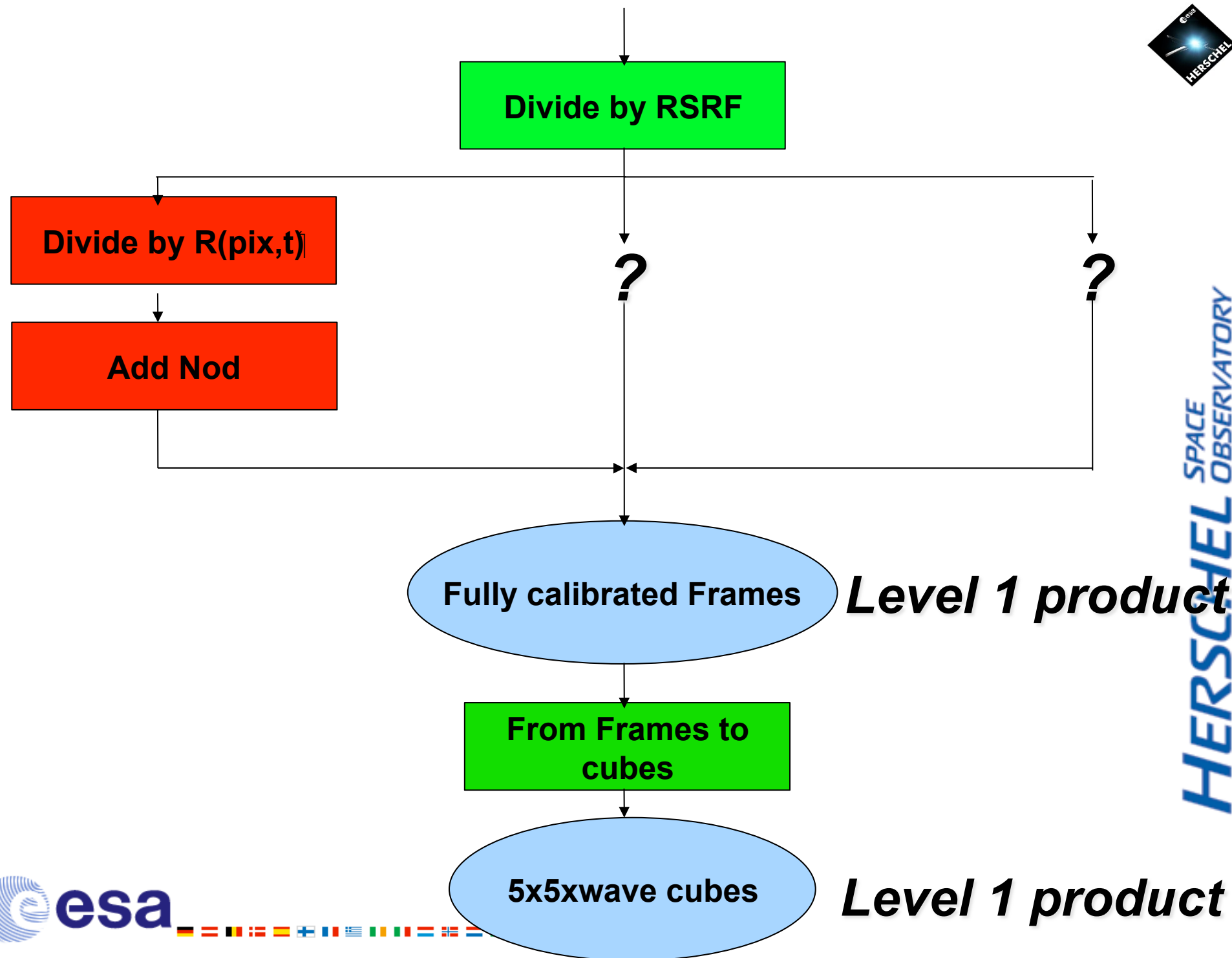
- ✱  $R(\text{pix}, t)$  derived using the off plateaux signal and assuming that the telescope background spectrum as measured in the mean of all pixels is not affected by response drifts:

$$\langle R(\text{pix}, t) / R(\text{pix}, t_{\text{cs}}) \rangle_{\text{pix}(i,j)} = 1$$

$$R(\text{pix}, t) = S_{\text{off}} / (\langle S_{\text{sky}} \rangle_{\text{pix}(i,j)} + \langle S_{T-} \rangle_{\text{pix}(i,j)}) \quad \text{Nod A}$$

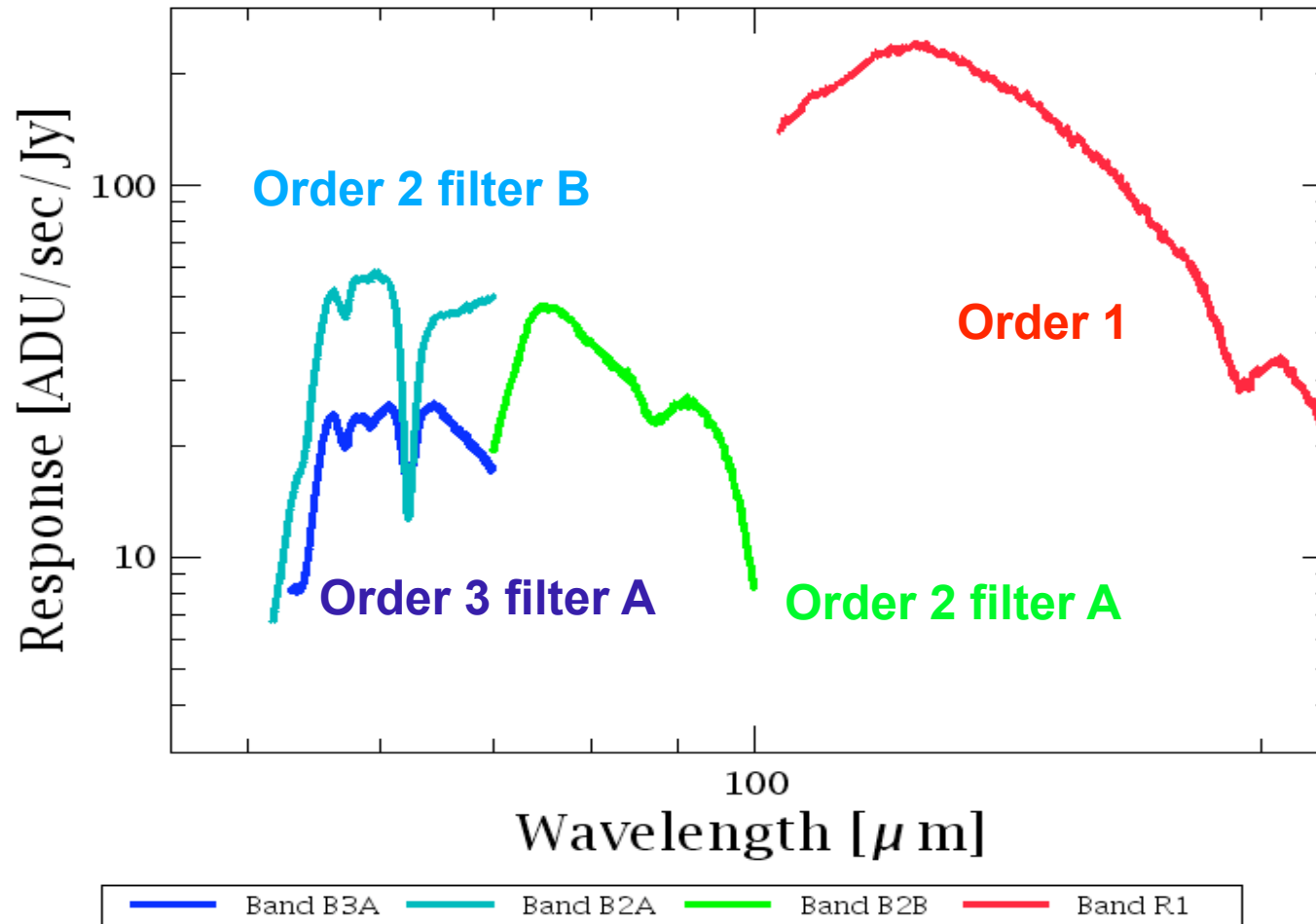
$$R(\text{pix}, t) = S_{\text{off}} / (\langle S_{\text{sky}} \rangle_{\text{pix}(i,j)} + \langle S_{T+} \rangle_{\text{pix}(i,j)}) \quad \text{Nod B}$$







# PACS RSRF: From ground tests



**NOTE: this is not relative!**

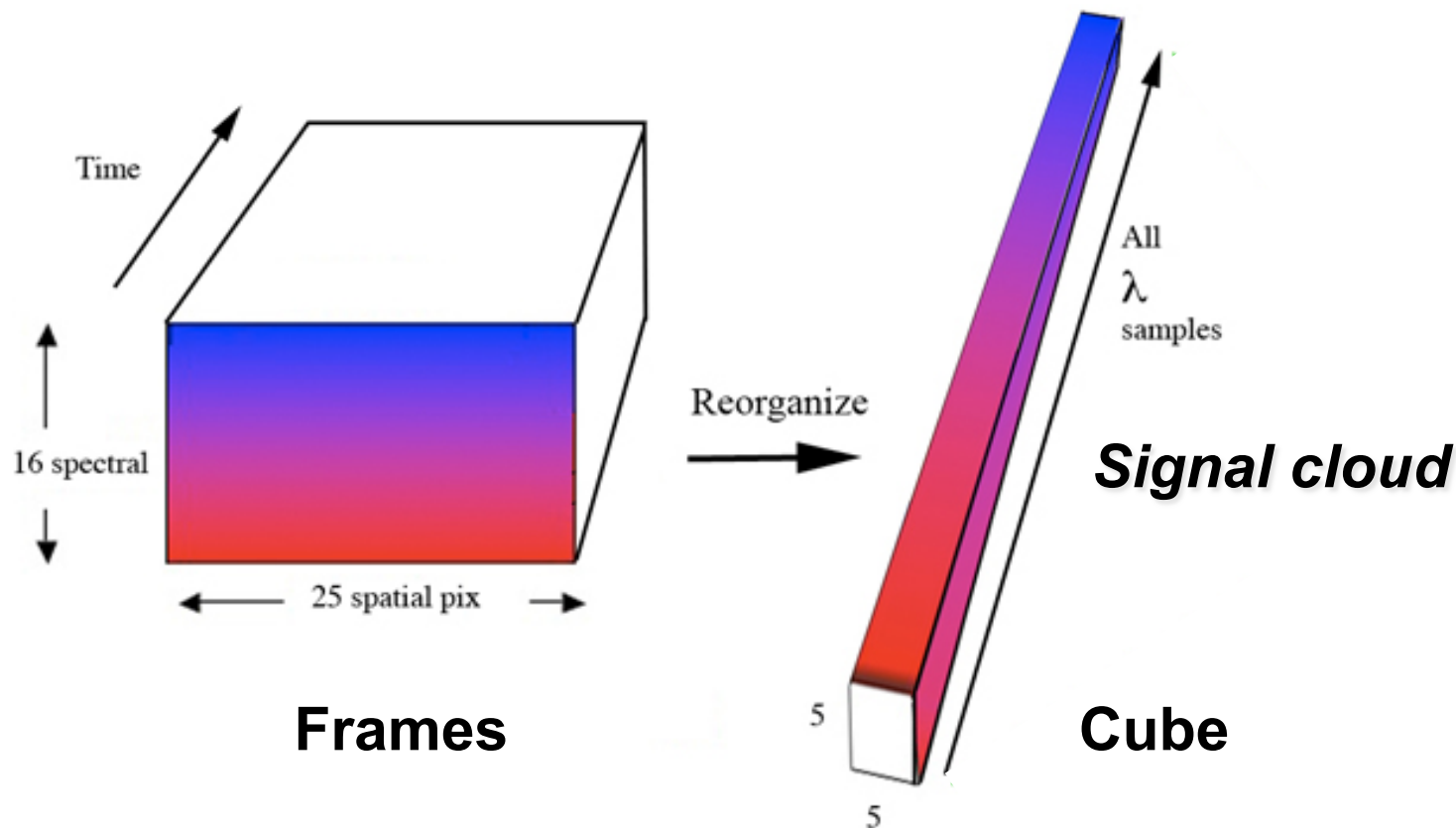
**We currently use it to flux calibrate**

**data. Will become relative a.s.a. new flux calibration  
concept in place**



# 2 Level 1 products!

## Same thing but different organization



$25 \times 16 \times N$   $\longrightarrow$   $5 \times 5 \times N \times 16$

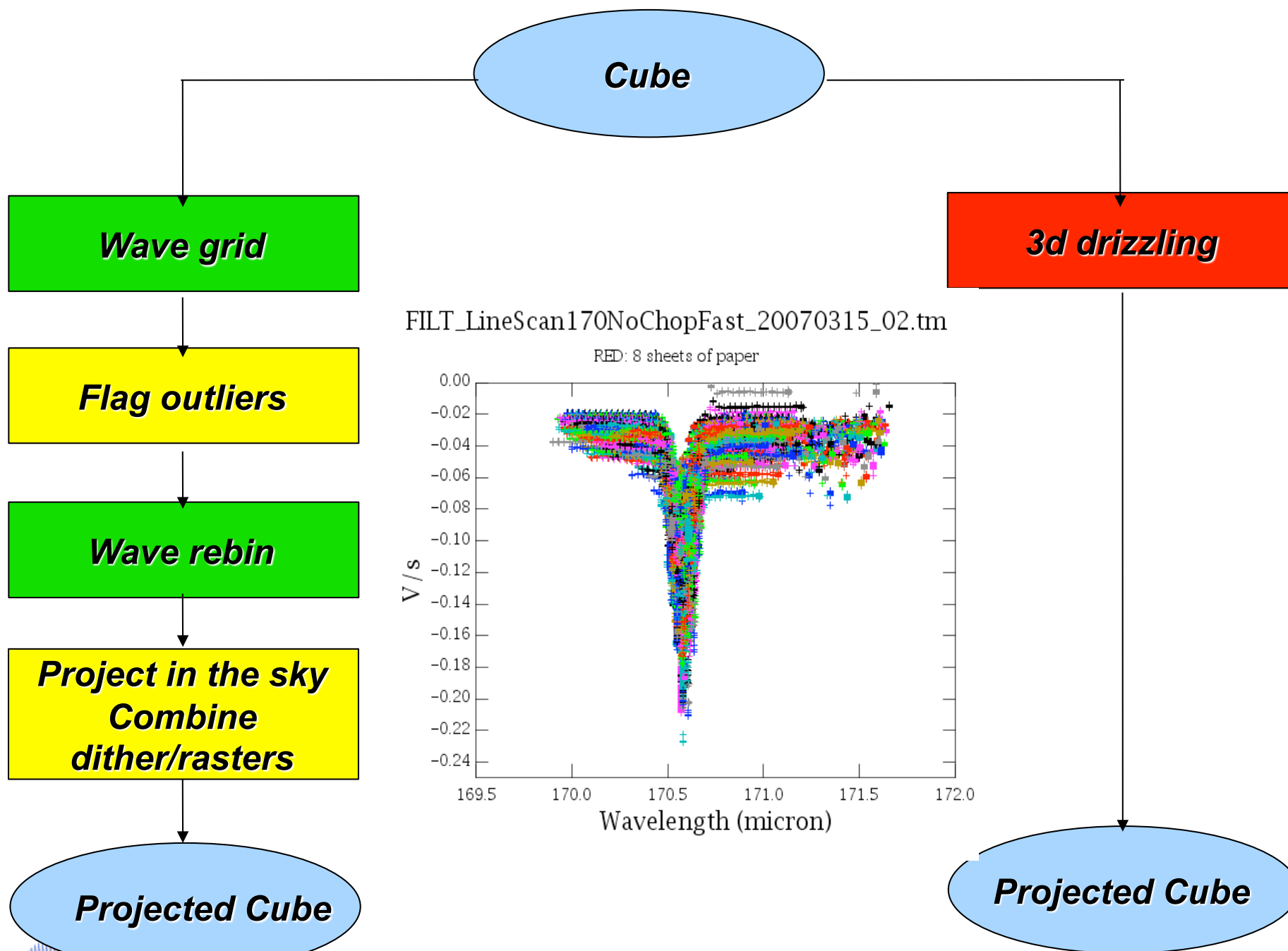
# From Level 1 to 2



Copyright © Randy Glasbergen. [www.glasbergen.com](http://www.glasbergen.com)

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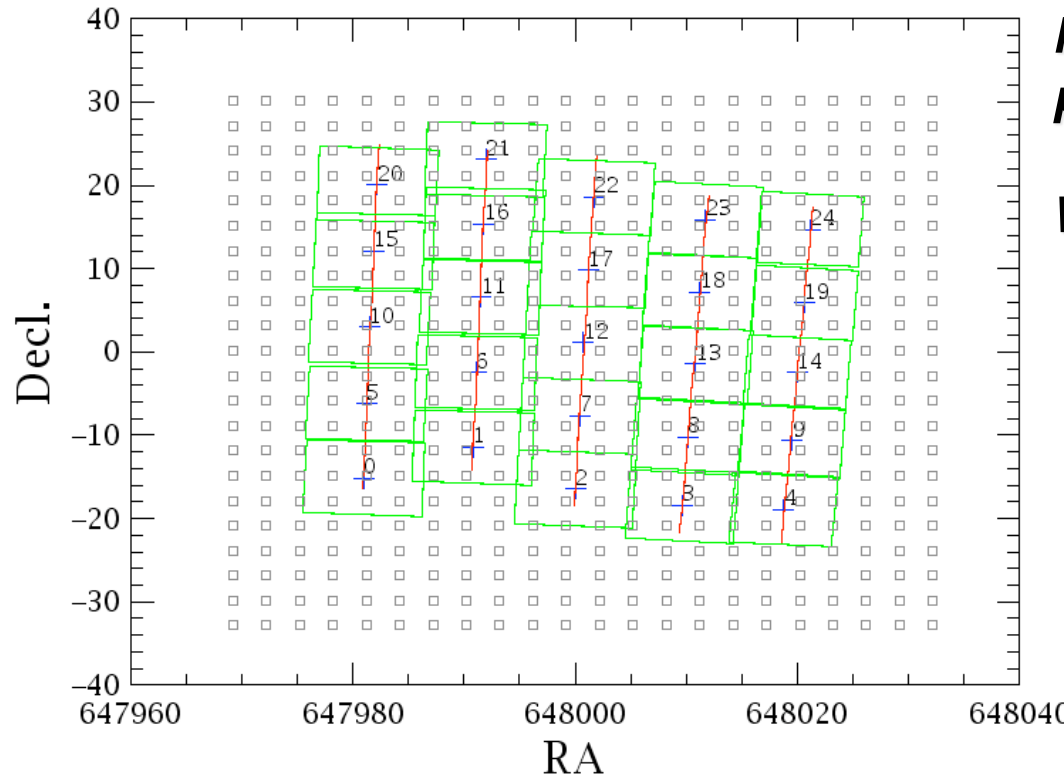
 **esa**  **Where user interaction becomes important**



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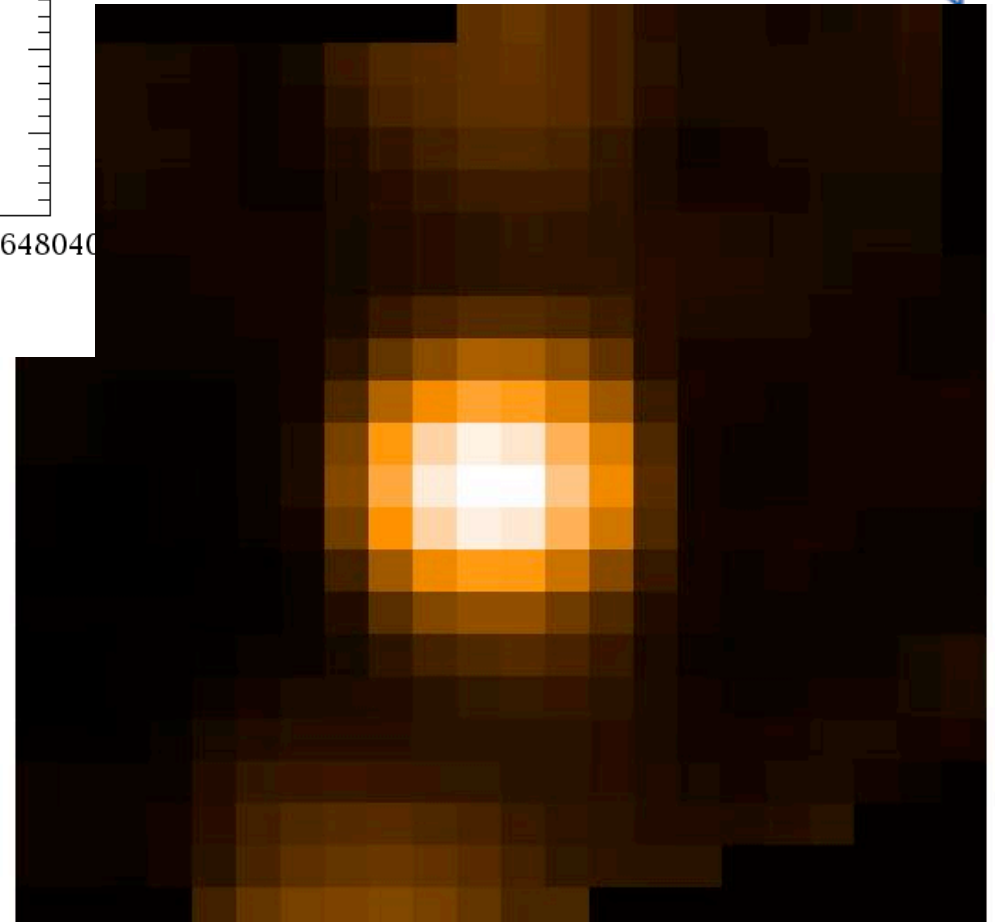
## Positions of modules and corners



***Messy spatial FOV;  
pixels not physically squared.***

***We have to regrid onto a regular grid***

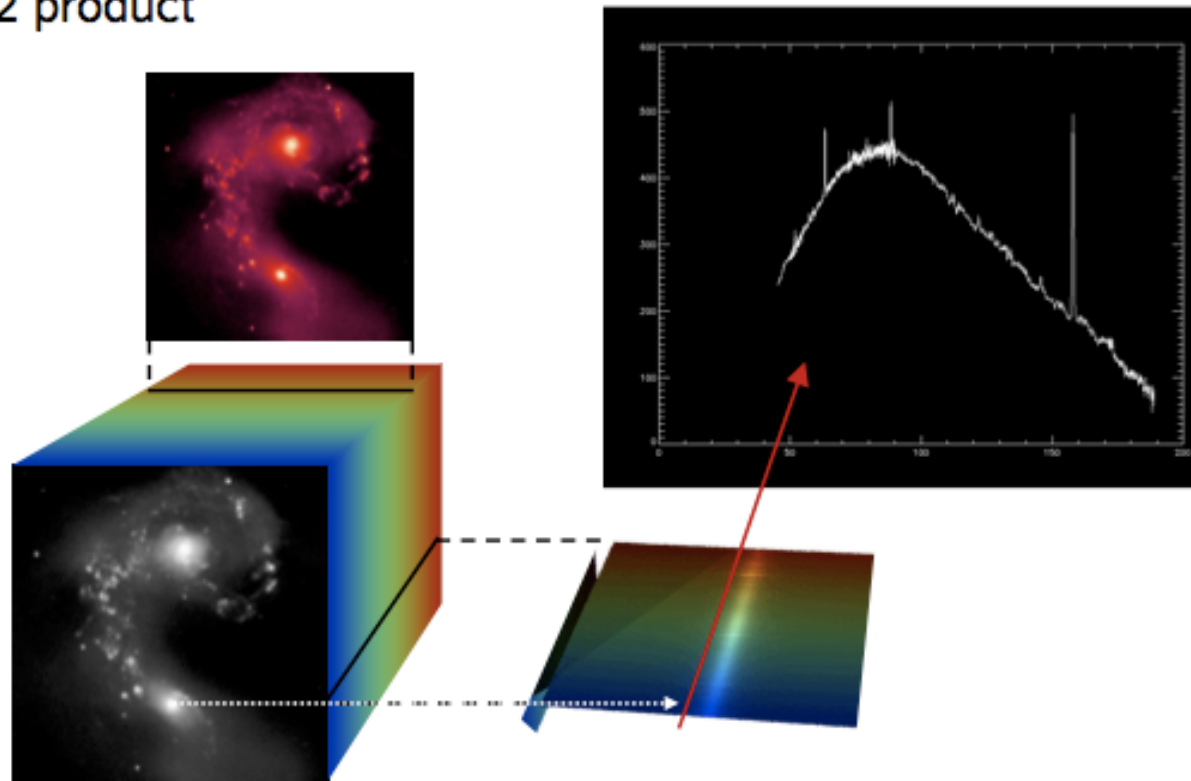
***Result of specProject on  
a ground based test data with  
a point source.***



# Rebinned cube and projected cube – Level 2



Level 2 product



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*Projected Cube*

- ☼ **Extract Spectra in regions and fit them**
- ☼ **Produce maps in lines and do photometry**
- ☼ **Point source extraction (Bright and weak)**

☼ ..... **your paper**

**LEVEL 3**

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# Summary status



- ✱ Most advanced pipeline for Chopped AORs (most test data in this mode)
- ✱ Flux calibration strategy for wave switch still to be defined
- ✱ Proper sky projection for well sampled maps now starting
- ✱ PACS Spec pipeline explained in a updated chapter of the UM



# Plans



- ✱ Advance in the wave switching pipeline:  
Flight Spare specific tests
- ✱ 3d drizzling algorithm testing
- ✱ Flux calibration strategy for map without chopping
- ✱ Data chunking @ Level 0 in logical blocks  
(could be necessary for big data set).
- ✱ Pacs data reduction guide: with reduction recipes for each AOR



# Things to keep in mind



- ✱ Signal behavior after glitch impacts will be fully characterized only AFTER launch
- ✱ AOR validation campaign in PV could lead to (some) AORs logic change. Impact on pipeline.

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# PACS Spectroscopy pipeline documentation

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# Detailed presentations of the December workshop:



http://herschel.esac.esa.int/DP\_workshop.shtml

**Herschel General Information**

- Herschel Science Centre Home
- Latest News
- Mission Overview
- Science Instruments
- Community Information
- Conferences/Workshops
- Press Releases
- e-News
- Useful links

**Herschel Observing**

- Introduction and Overview
- Documentation
- Tools
- Key Programmes
- Latest AO

**Herschel Data**

- Data Processing
- Data Products
- Science Archive

**Herschel User Services**

- Services Overview
- Helpdesk
- Proposal Handling
- Subscribe to Herschel eMail list

**Herschel User Registration**

- User Registration
- Lost/Broken Password ??

**Herschel Pre-Launch Data Processing Workshop**

ESAC, 4-5 December 2008

**Workshop generalities**

- Final Agenda (PDF 17kb)
- List of Participants (PDF 14kb)

**Presentations**

- The Herschel Data Processing System: History, Status and Plans (S. Ott) (PDF 1.9Mb)
- Herschel DP Status and Plans: the User's point of view (B. Merin) (PDF 1.5Mb)
- Installing HIPE (M. Kidger) (PDF 1.2Mb)
- Help Documentation and Search Capabilities in the Herschel DP System (A. Marston) (PDF 695kb)
- Getting Data from the Herschel Science Archive (E. Verdugo) (PDF 155kb)
- HIPE Pipelines and Data Products (A. Boogert) (PDF 10Mb)
- PACS Photometry Data Processing and Calibration: Processing up to Maps (P. Popesso) (PDF 2.8Mb)
- PACS Spectrometer: Instrument, AOTs, Observing Modes (R. Vavrek) (PDF 2.8Mb)
- PACS Spectrometer: Concept, Status, Plans (A. Contursi) (PDF 3.7Mb)
- SPIRE Spectrometer Pipelines and Data Products (E. Polehampton) (PDF 1.9Mb)
- SPIRE Photometer Pipelines and Data Products (P. Panuzzo) (PDF 1.2Mb)
- HIFI Deconvolution Tool Demo (S. Lord) (PDF 810kb)
- Visualisation and Manipulation Tools for Herschel Spectra (R. Shipman) (PDF 1.9Mb)
- Visualisation and Manipulation Tools for Images (S. Regibo) (PDF 29kb)
- Visualisation and Manipulation of Spectral Data Cubes (A. Gueguen) (PDF 535kb)
- Point Source Extraction Tool (A. Smith) (PDF 2.2Mb)

# PACS Spectroscopy pipeline documentation in HIPE: short HowTo



HCSS Help System

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**6.4. SPEC pipeline**

Full PACS pipeline documentation explaining the tasks being performed in each module is provided elsewhere. Here we show the steps. Note that what was called "myobs" above is here called "ramp". The data reduction from level 0 to 0.5 are the same for all types of observation.

**6.4.1. Level 0 to 0.5: ramp to frame**

First you need to tell HIPE about the calibration tree you will use. This contains the information to be used in the calibration conversions used in the PACS pipelines, and it comes with your observation when you get it from the HSA. It appears as a folder called "calibration" viewable in HIPE when viewing the contents of your "prod\_12" (not "myobs"). In order to get the calibration information associated with a given observation, the user simply uses the command:

```
mycaltree = getCalTree()
# and to see it either click on it in Variable panel or
print mycaltree.spectrometer
```

The next steps are to: decode the label (translate mechanism position data into observing blocks and add to the "status" table for your ramp); apply various flags; convert the data to units of volt/s; fit the ramps:

```
ramp = decodeLabel(ramp)
ramp = specFlagBadPixelsRamps(ramp, calTree=mycaltree)
ramp = cleanPlateauRamps(ramp, calTree=mycaltree)
ramp = flagGratMoveRamps(ramp, calTree=mycaltree)
ramp = specFlagSaturationRamps(ramp, pacsCalTree=mycaltree)
ramp = specConvDigit2VoltsRamps(ramp, calTree=mycaltree)
frame = fitRamps(ramp)
# to inspect the masks created just above you can use a mask viewer. first import
from herschel.pacs.signal import MaskViewer
# and then
MaskViewer(frame)
```

The next set of tasks do the following: convert digital chopper positions to angle on the sky; extract RA and Dec from the pointing product for the central pixel; assign RA and Dec for every pixel (performs a spatial calibration); add information to the status table; created a summary of the logical blocks in the measurement.

```
frame = convertChopper2Angle(frame, calTree=mycaltree)
frame = specAddInstantPointing(frame, prod_12.auxiliary.pointing, calTree=mycaltree)
```



# PACS Spectroscopy pipeline documentation in HIPE: SPG description in PACS User's Manual



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## Chapter 12. PACS spectroscopy standard data processing

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HERSCHEL SPACE OBSERVATORY



# Hands-on session: Run the pipeline

**HERSCHEL** SPACE  
OBSERVATORY

# Before starting the hands-on session



- ***Be sure you have installed***

- ✓ HIPE 0.6.7.1 [http://herschel.esac.esa.int/HIPE\\_download.shtml](http://herschel.esac.esa.int/HIPE_download.shtml)
- ✓ In your workingdir = "~/.../Data/" specified in your demo script put
  - Demo script `demo2script_pacsSpectroChopNod_24032009.py`
  - Simulated OIII line `demo2simulatedFrames_pacsSpectroChopNod_24032009.fits`
- ✓ In your ~/.hcss/lstore deploy the tarball and create a Local Store of Observation Context for OBSID 3221226016:

`~/.hcss/lstore/demo2LocalStore_pacsSpectroChopNod_24032009`

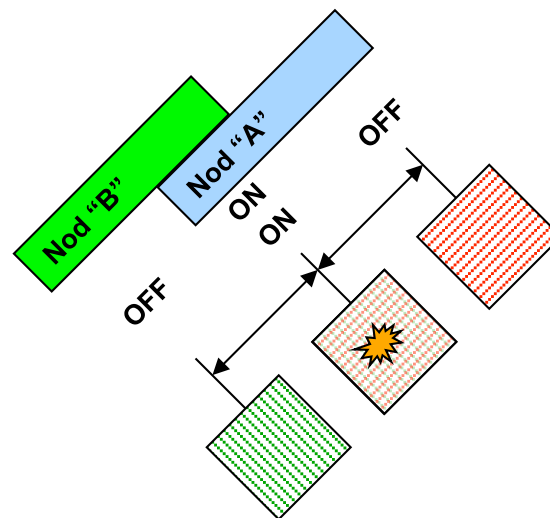
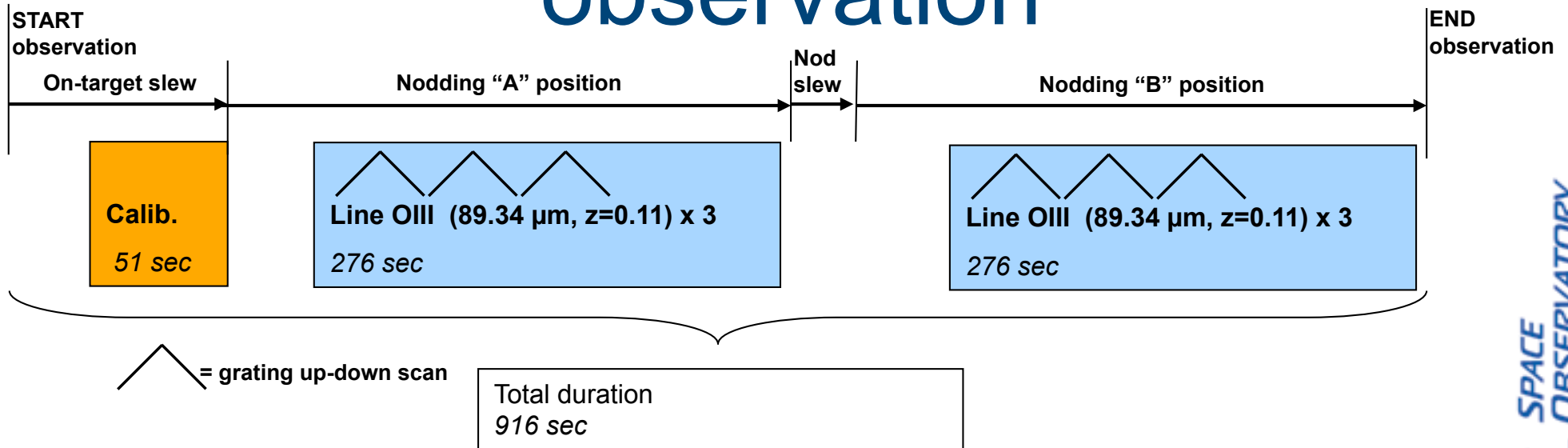
# Goals of this interactive session



- Access Level 0 data (from Observation Context)
- Run PACS chop/nod pipeline up to Level 2
- Analyse data on Level 2
- Create plots and prints of intermediate L0-L2 products
- Read, manipulate and plot calibration products
- Overview on PACS product structure (what is in meta data, Status and BlockTable data sets, dimensions of science data set through reduction steps...)
- Create product history
- I/O:
  - Save/read data in/from Local Store
  - Save/read products to/from Fits file

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# AOT blocks of the demo observation



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# Data volume

For LEVEL0 data (herschel.pacs.signal.ARamps):

70M hpacss3221226016\_00HPSAVGBS\_2v1.fits  
70M hpacss3221226016\_00HPSAVGRS\_0v1.fits

For LEVEL0 data (herschel.pacs.signal.TRamps):

24M hpacss3221226016\_00HPSRAWBS\_3v1.fits  
24M hpacss3221226016\_00HPSRAWRS\_1v1.fits

For LEVEL1 data (herschel.pacs.signal.Frames) :

8.4M hpacs00000001hps3d\_20081202T182353657Z.fits  
8.4M hpacs00000001hps3d.fits

For LEVEL2 data (herschel.ia.dataset.image.SimpleCube) :

20K hsimplecube\_20081202T182350429Z.fits  
20K hsimplecube.fits

CALIBRATION and auxiliary data:

~700M but this will collapsed in future calibration data  
management



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# Try to explore the pipeline by yourself: exercise



- Select the first up-scan from “frame” and copy it into “framesel” 2
- Plot signal vs. wavelength for pixel [8,12]
- Create rebinnedCube for the first up-scan
- Plot signal vs. wavelength for pixel [2,2]

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