PACS Spectroscopy pipeline and data products

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

Speaker: Roland Vavrek (HSC)

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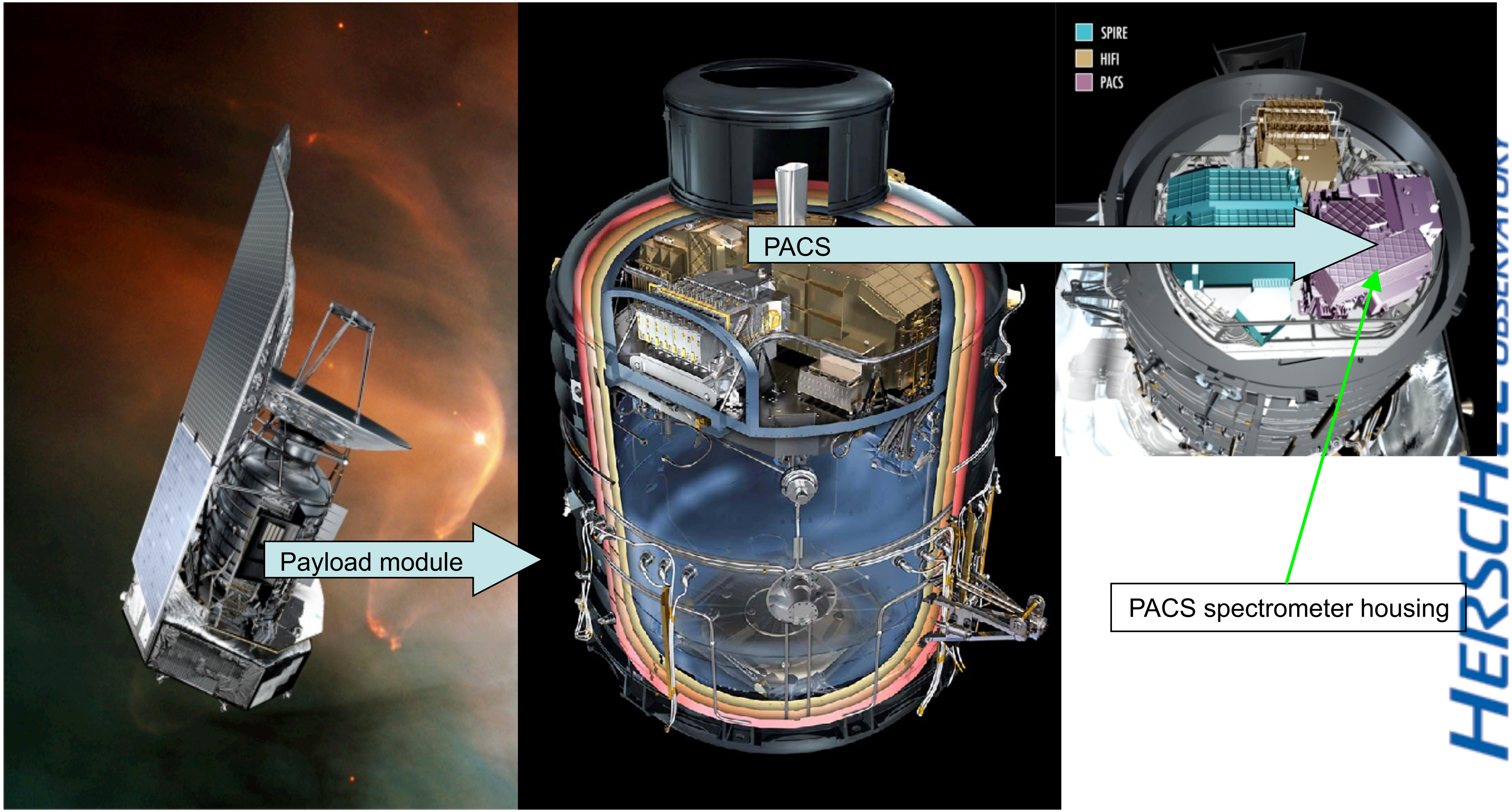
and the PACS ICC

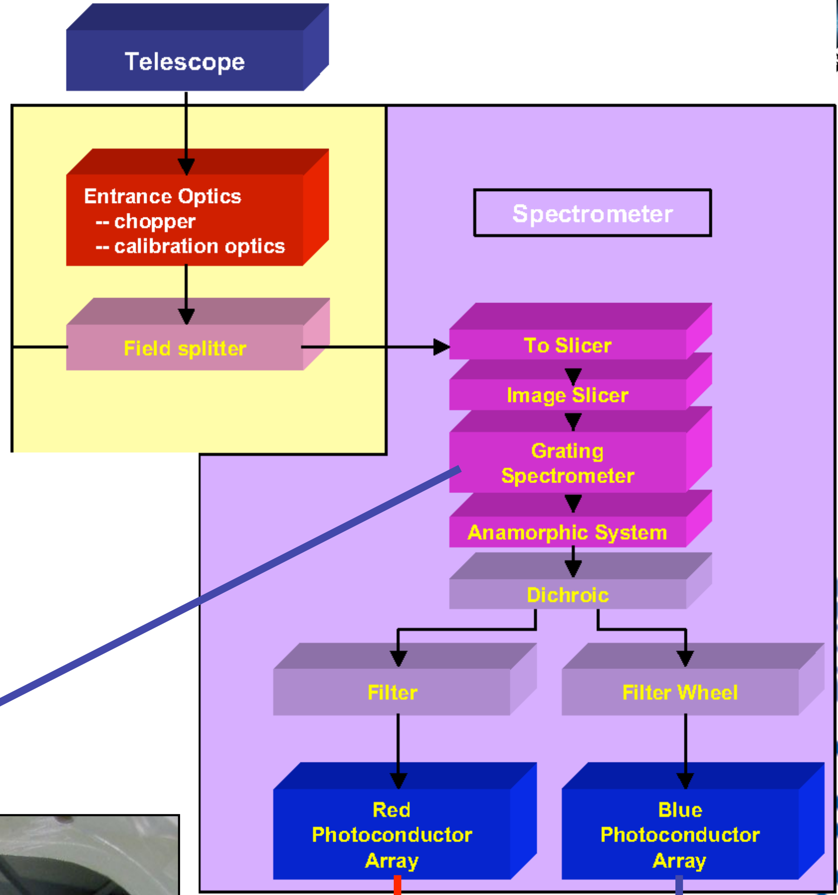
Outline

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

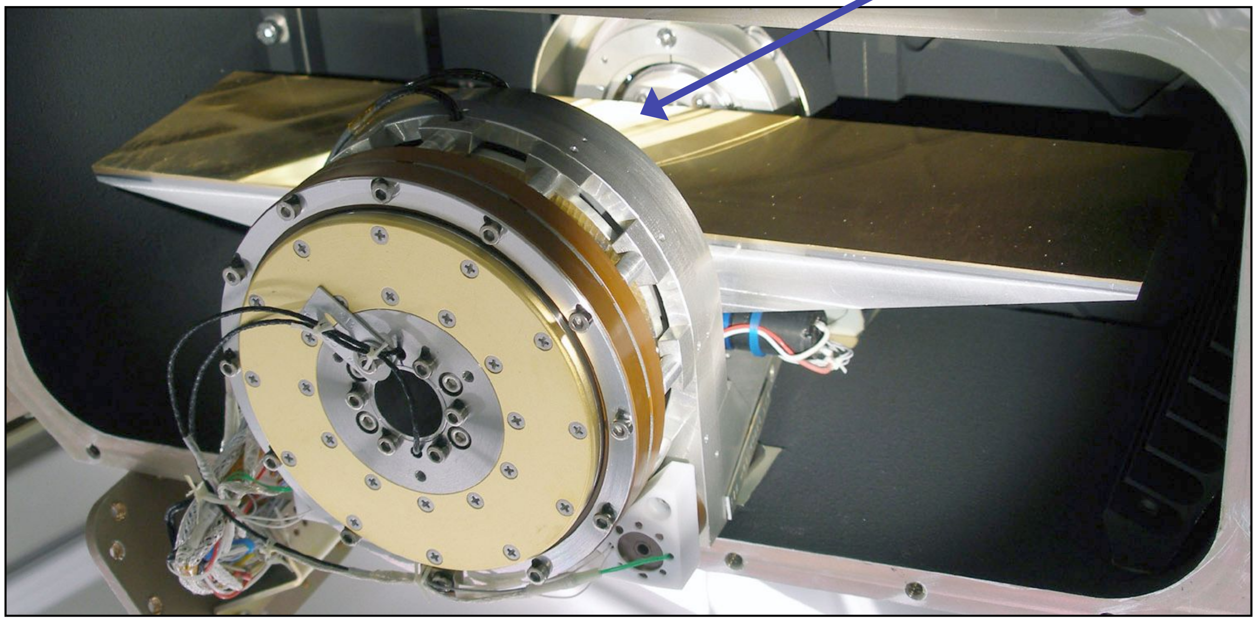
PACS Spectrometer concept

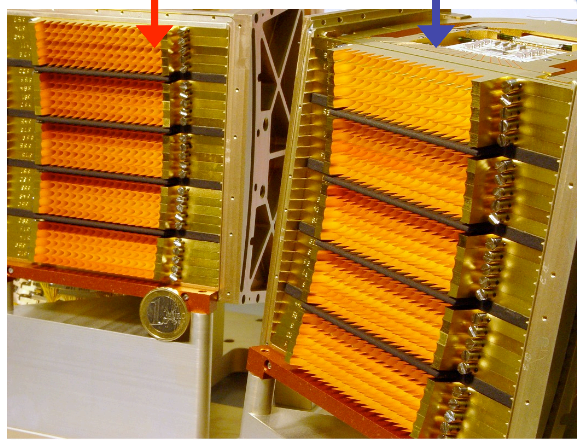


Diffraction grating spectrometer with high- and low-stressed Ge:Ga detector arrays

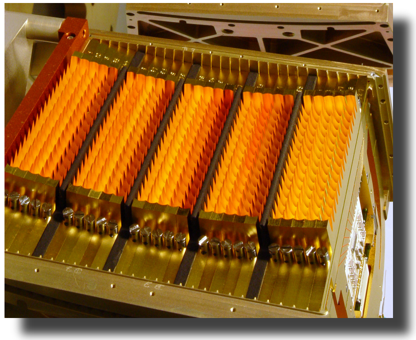


Grating: diffraction element used in 3 orders

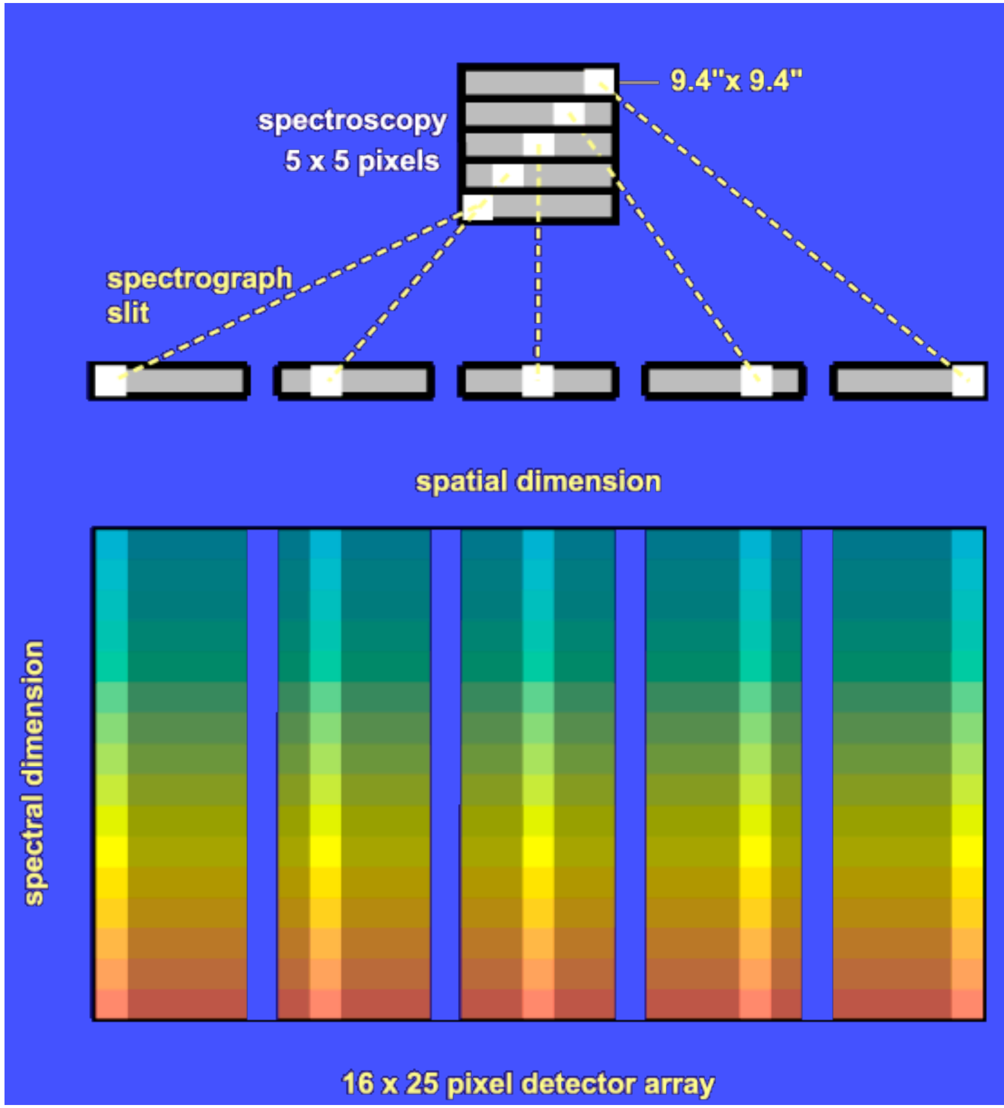




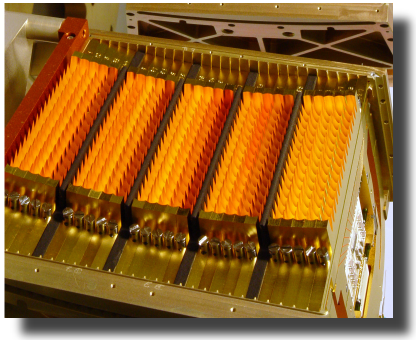
Integral-field concept

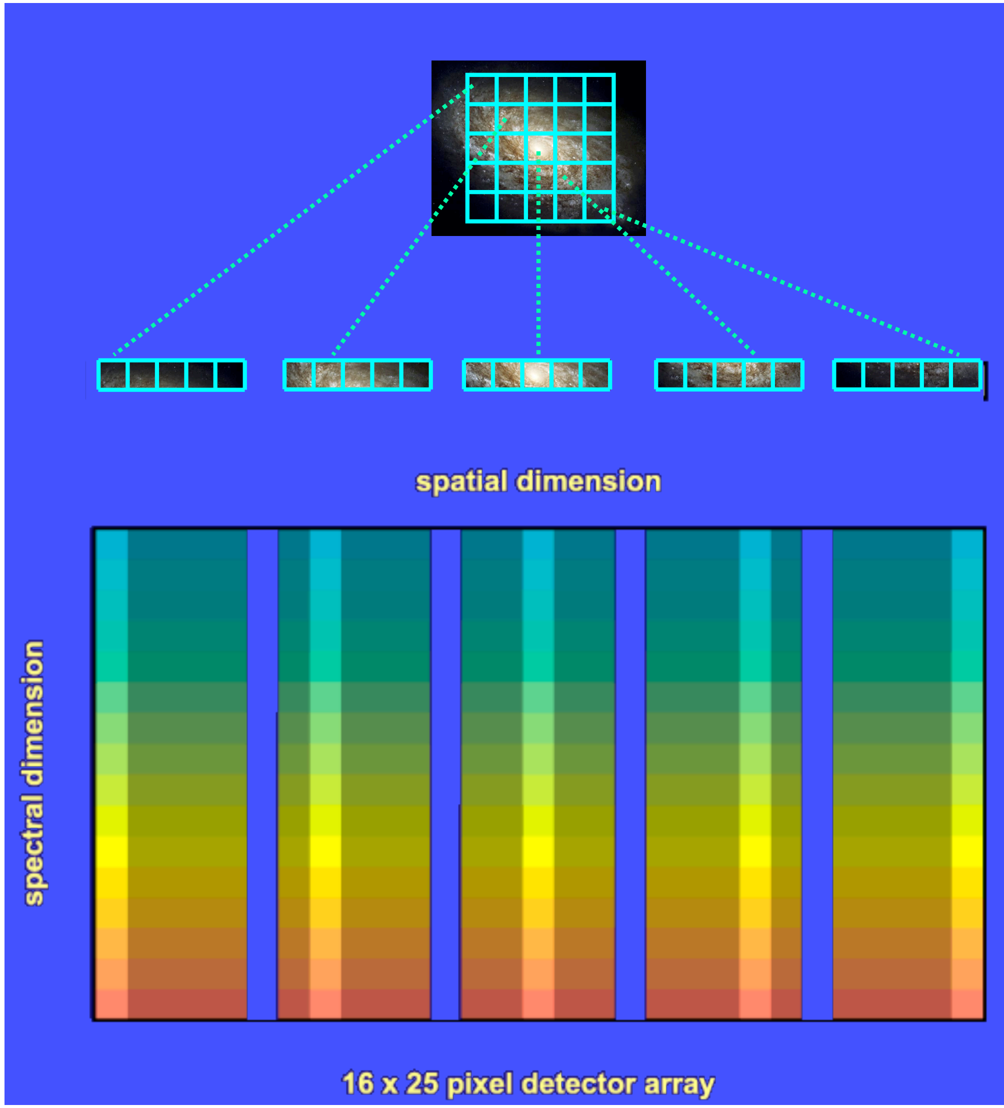


47"x47" (5x5 pixels) FOV rearranged via an image slicer on two 16x25 detector arrays



Integral-field concept

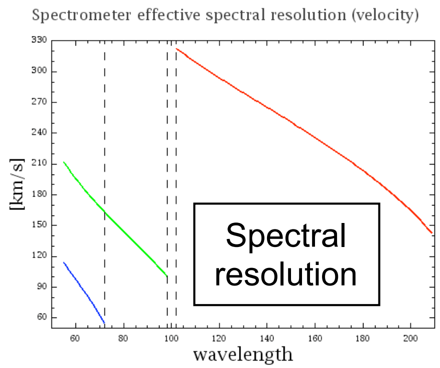


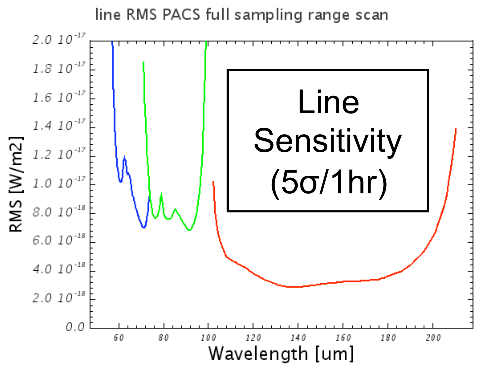


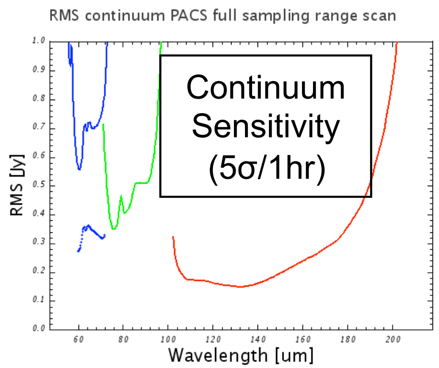
- Simultaneous 55-98 & 102-210 µm spectroscopy
- Performance:
  - λ/Δλ ~ 1500
  - Sensitivity: ~5x10-18 W/m2 (5σ, 1h)

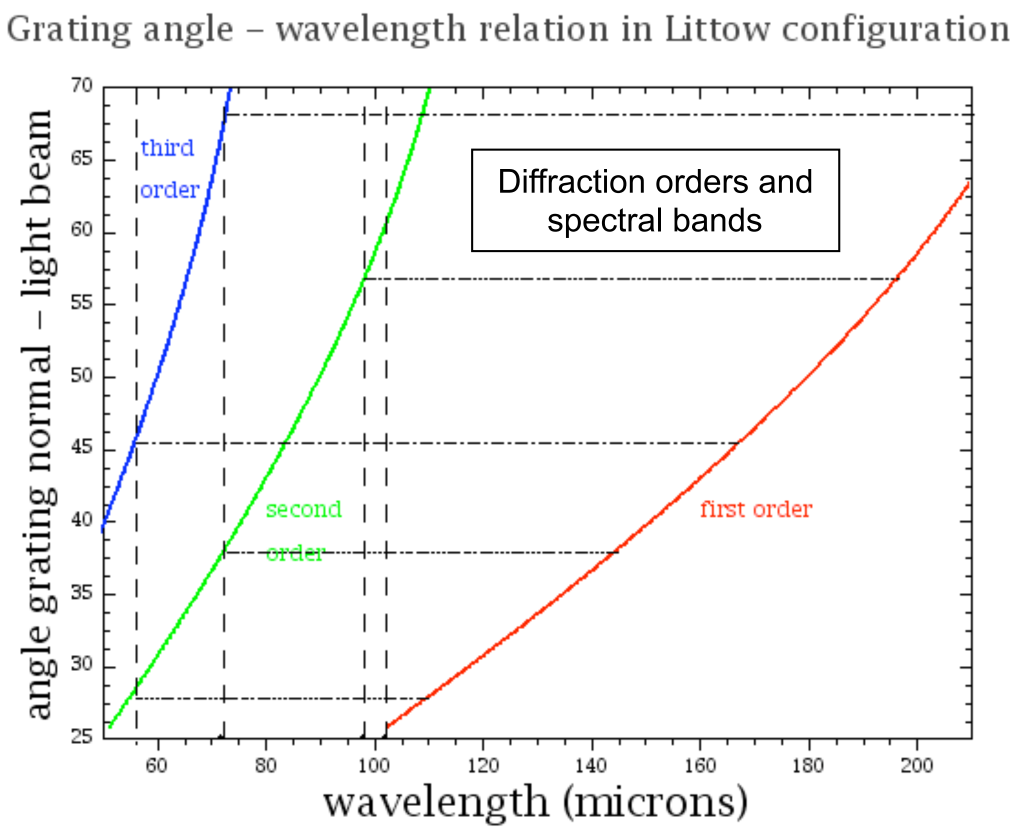
PACS presents: Death of Photon

PACS spectral bands

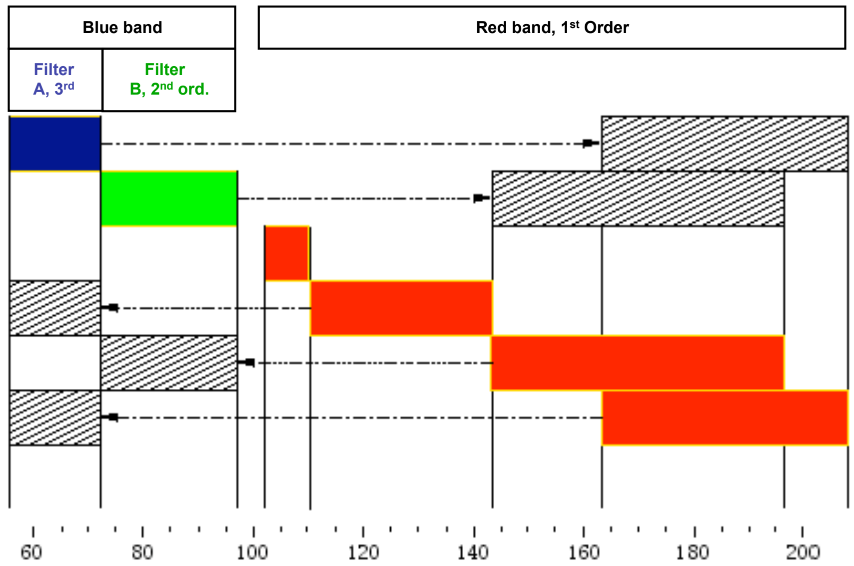








Nominal bands and parallel data



Spectrometer Astronomical Observing Templates (AOTs)

Signal modulation Techniques

- **Line Spectroscopy AOT:** ***observation of individual narrow lines:***
  - **Chopping/nodding**
    - Pointed, dithered and mapping modes
    - For isolated sources and rasters ≤ 6 arcmin
    - Variable grating sampling for faint and bright lines
  - **Wavelength switching**
    - For mapping observations of crowded fields
    - Mandatory off-position

Range definition

Signal modulation Techniques

- **Range Spectroscopy AOT:** ***observation of extended ranges, broad lines or continuum***
  - **Range scan** (same concept as Line Spectroscopy) *for broad lines*
  - **SED** mode (1st and 2nd orders [71-98,102-210 μm] or 3rd order [55-73 μm]) *for continuum*
  - **SED blue sensitive** mode (extended 2nd order [60-73 μm]) *for continuum*
  - **Nyquist sampling** same as SED mode for restricted ranges *for continuum and bright lines*
  - **Chopping/nodding**
    - Pointed, dithered and mapping modes
    - For isolated sources and rasters ≤ 6 arcmin
    - For broad lines, multiple line coverage or continuum studies
  - **Off-position**
    - For mapping observations of crowded fields

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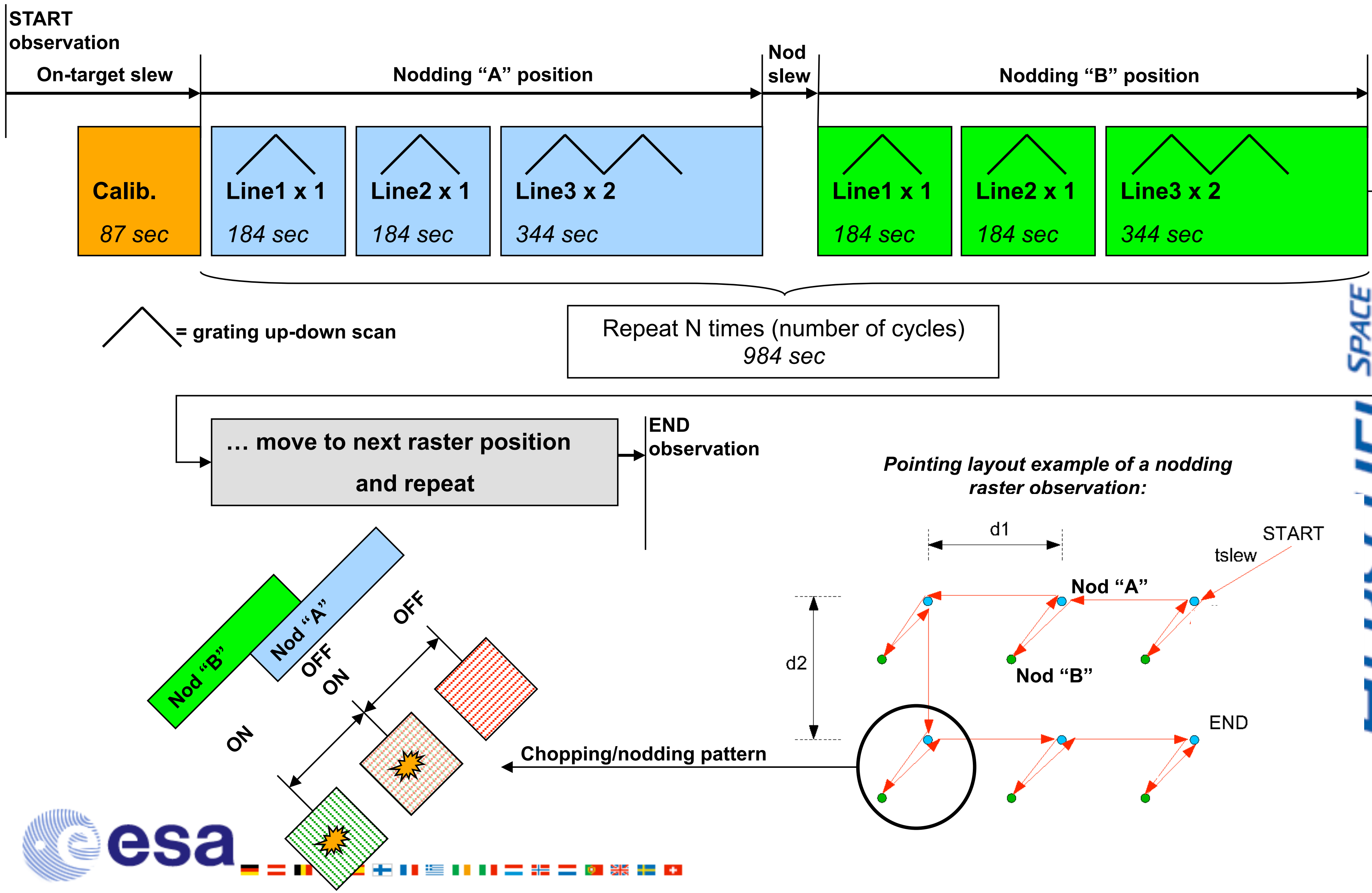
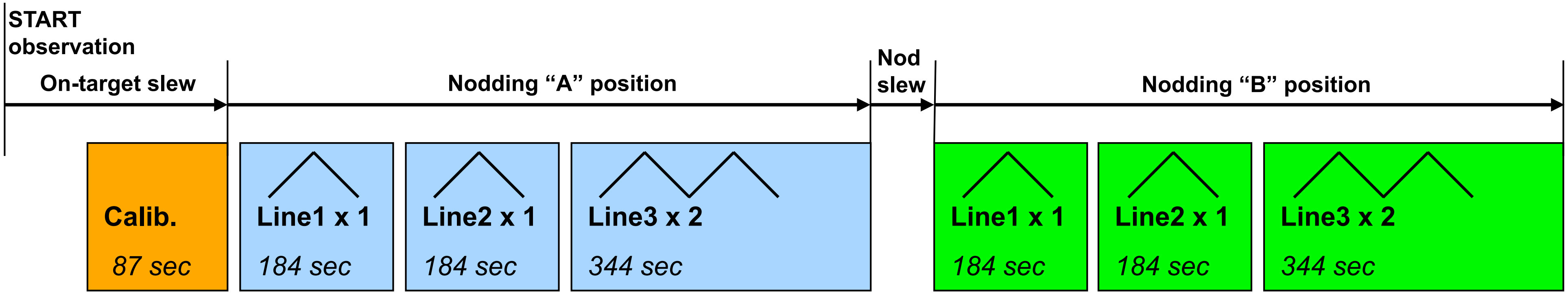
esa

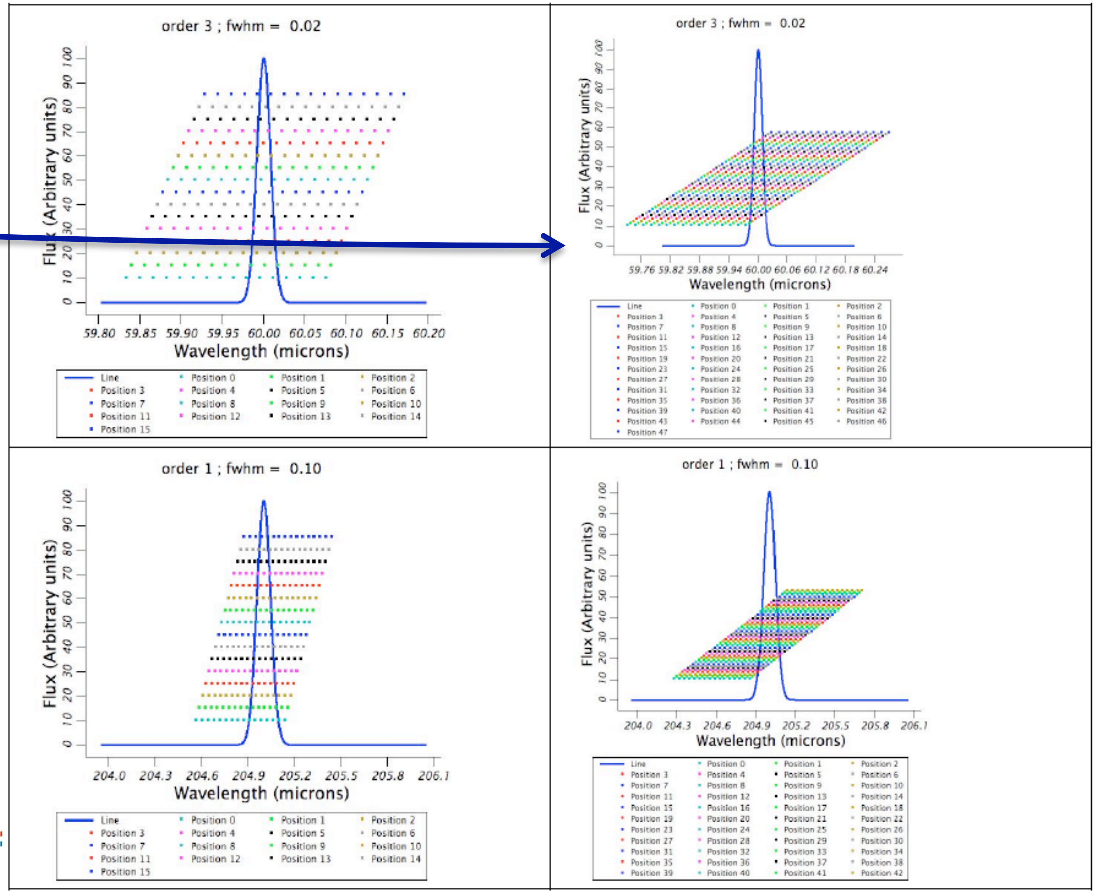
Chop/nod AOT blocks



Chop/nod AOT blocks

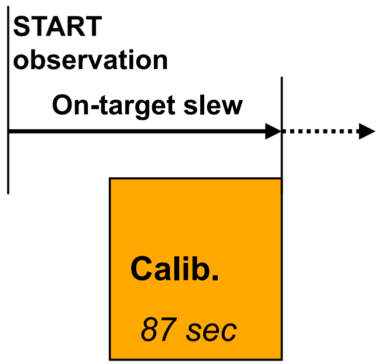


= grating up-down scan

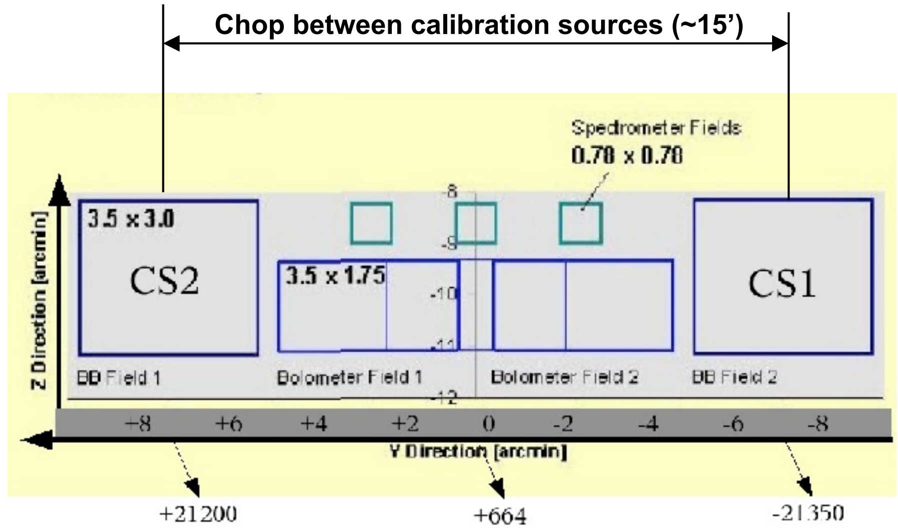


Grating sampling in a single up-scan for bright line and high sampling modes

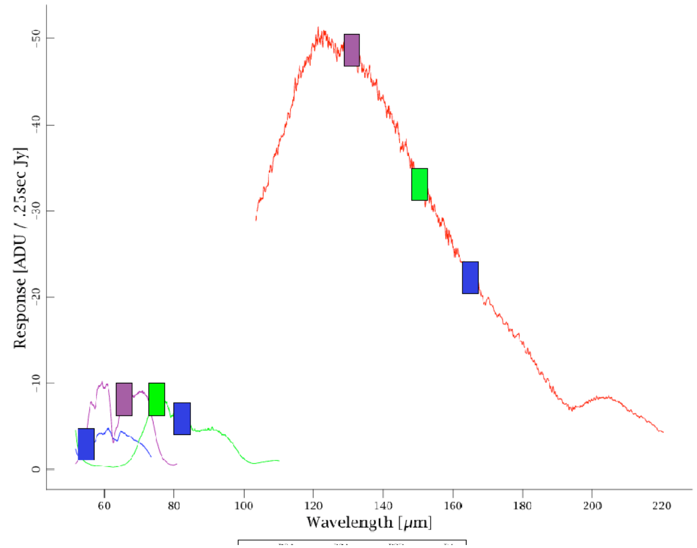
AOT calibration block



- 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



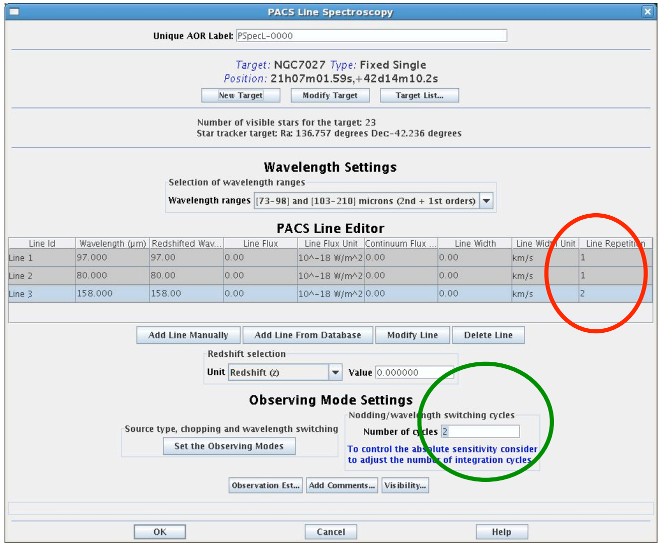
Key wavelengths
on the Relative Spectral Response Function (RSRF)



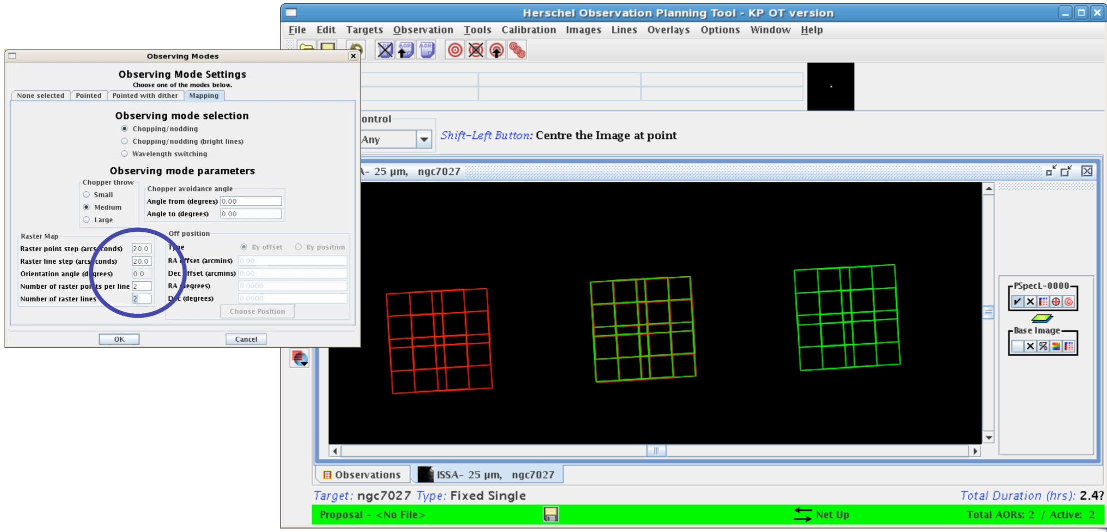
… and how blocks are defined in HSpot

Nodding blocks

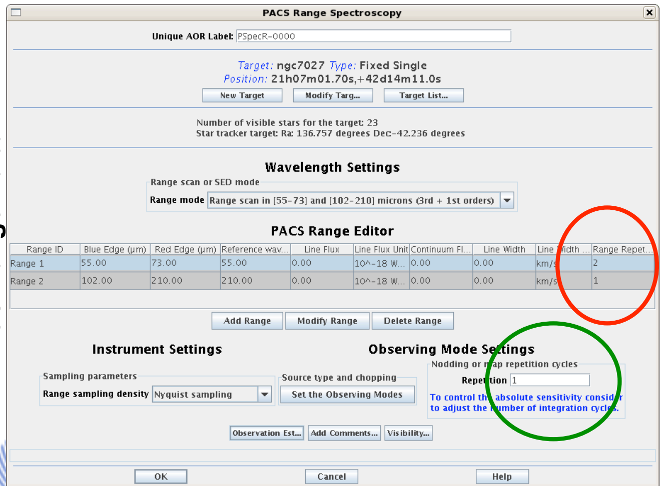
PACS Line Editor



Pointing blocks



PACS Range Editor



Depth of the observation is set via repetition factors:

- *Line/Range repetition for relative Line/Range strength, total number of repetitions is ≤ 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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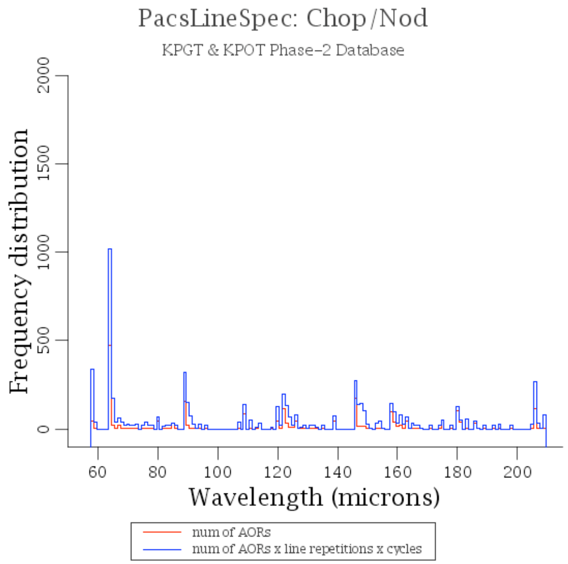
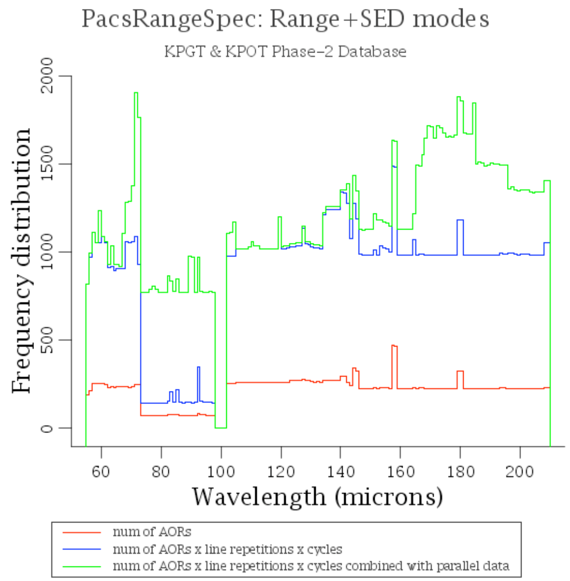
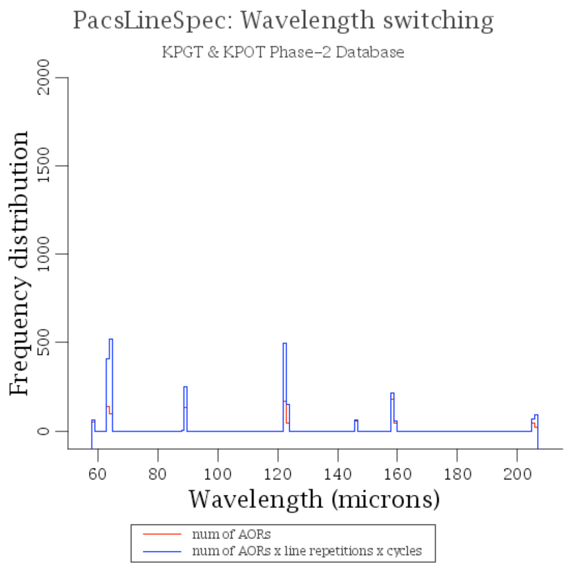
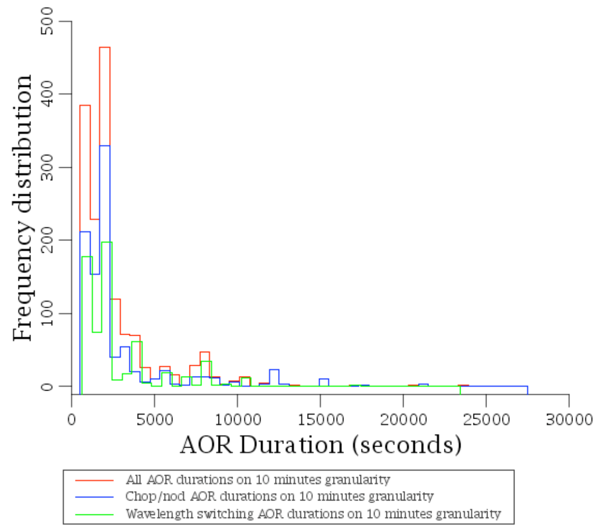
Spectroscopy observing modes
Key Programmes statistics

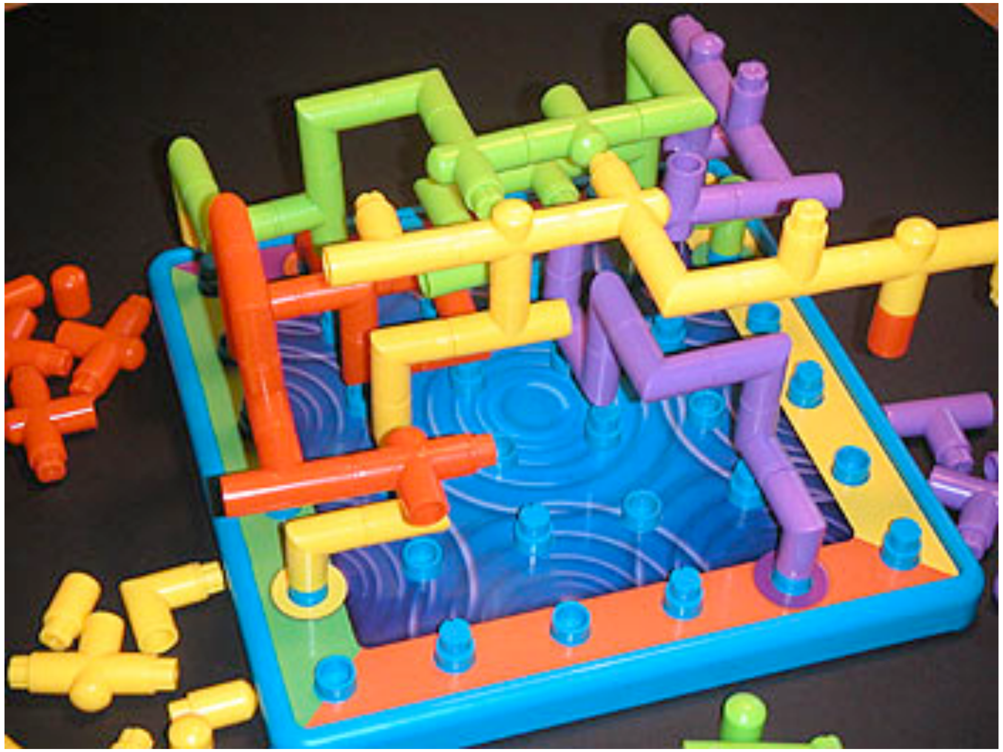








Pipeline and products



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

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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

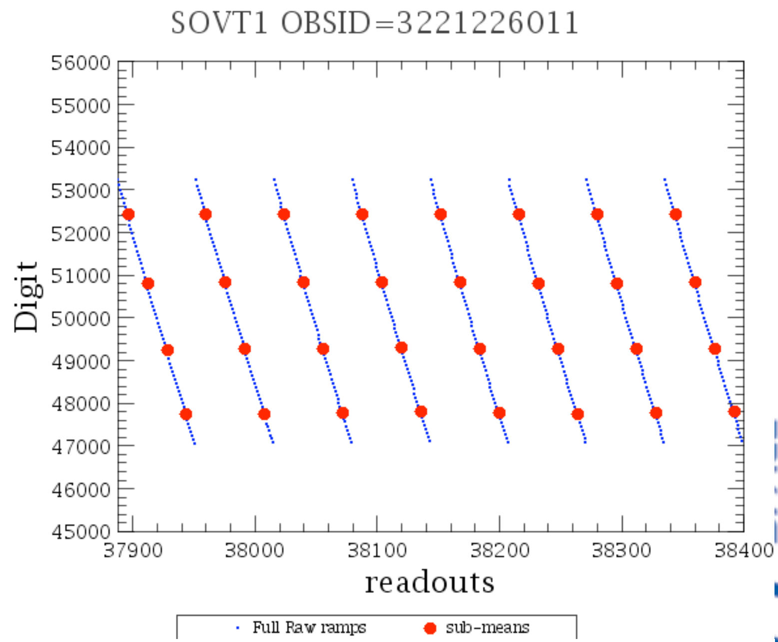
Pipeline input data

Level 0 Products

Raw telemetry

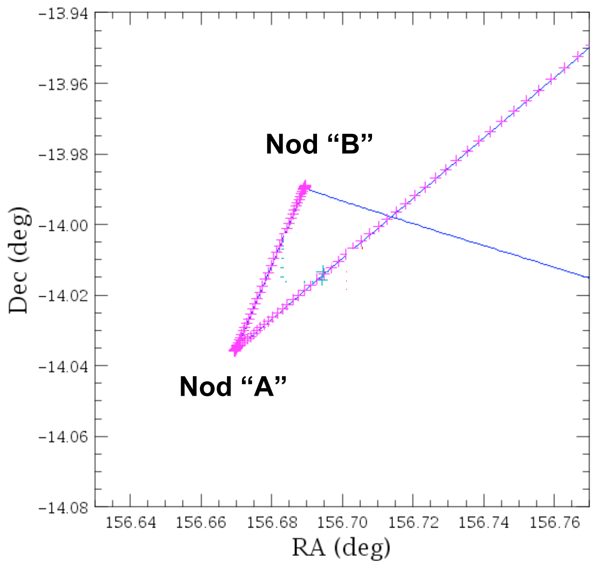
- Science data
- Housekeeping
- Pointing

on-board averaged data



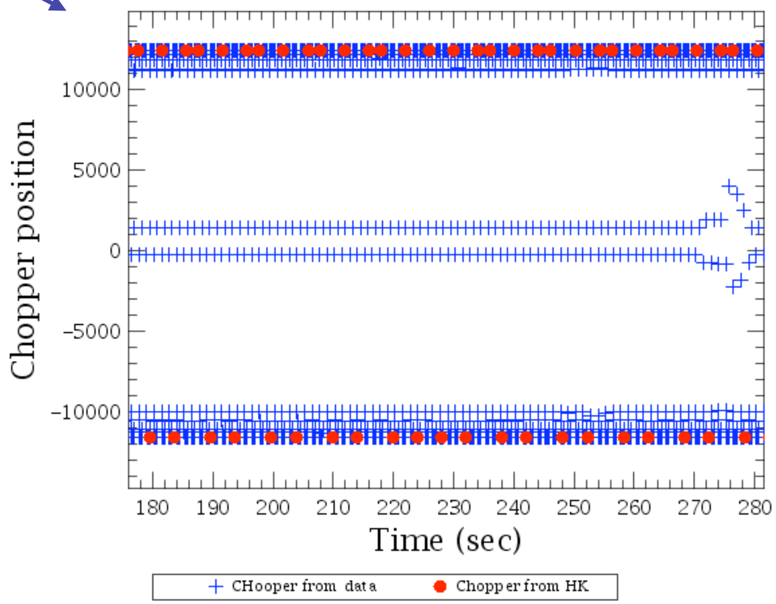
e.g. mechanism positions

Telescope boresight attitude info

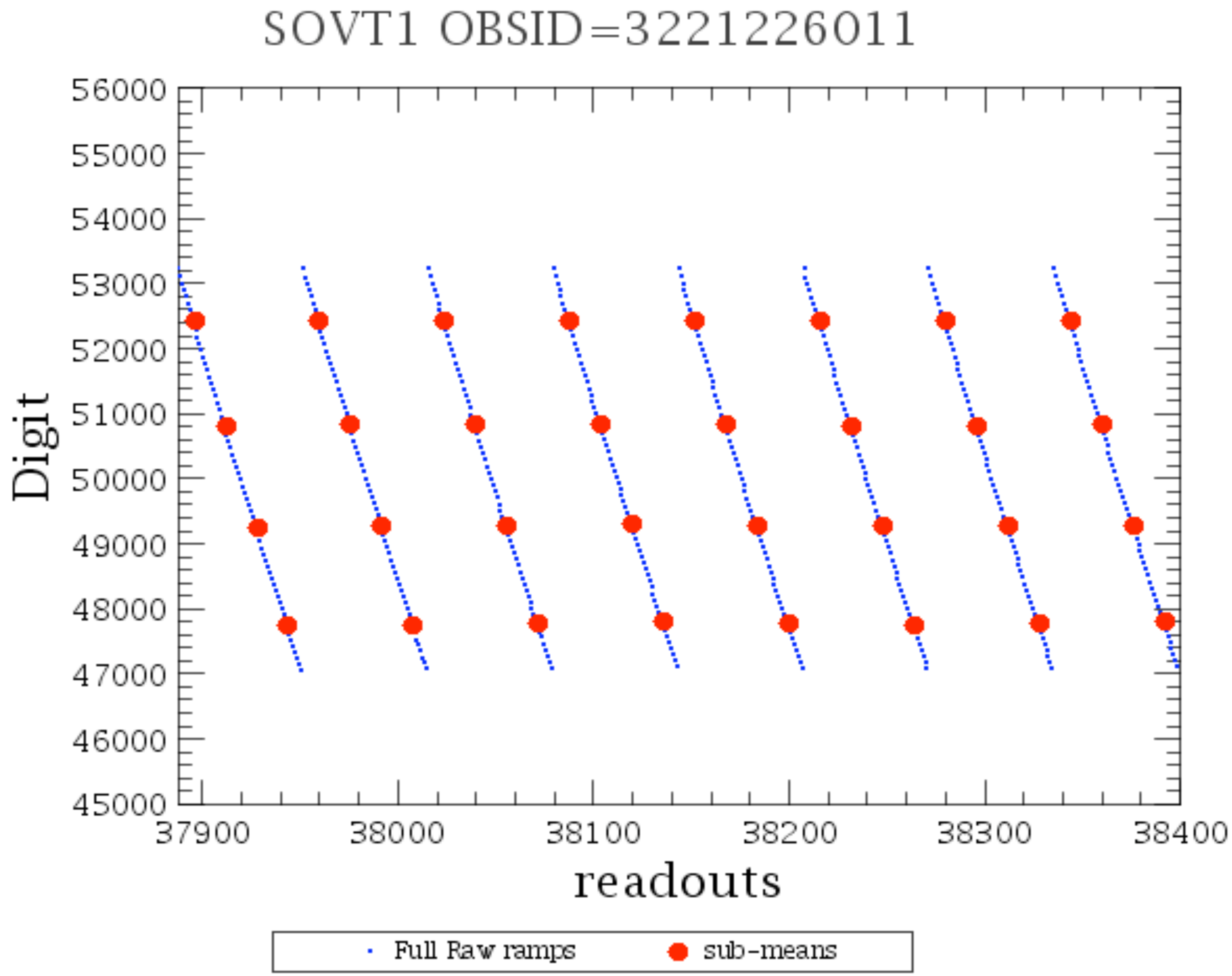


Some of the HK data essential for data reduction are associated with science data at high time resolution e.g.:

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



Raw data: ramps with sub-means

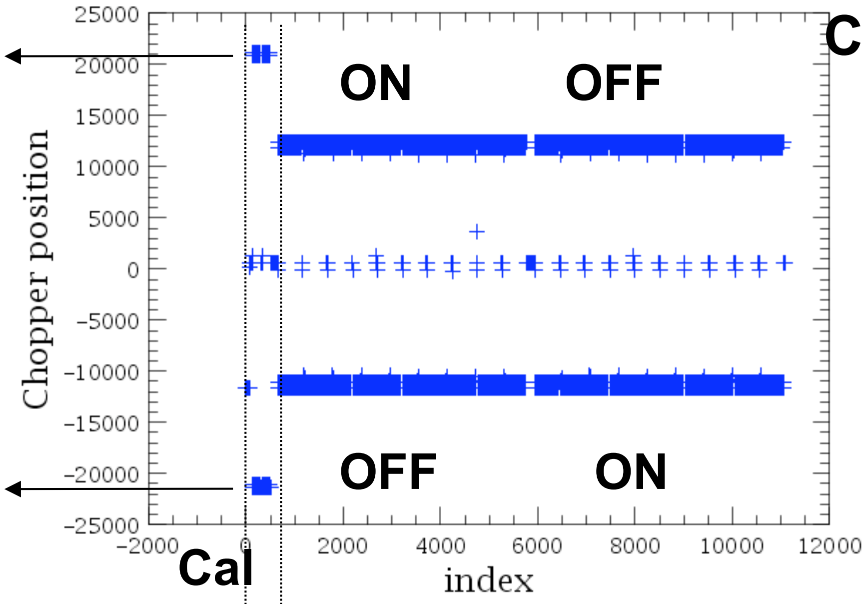


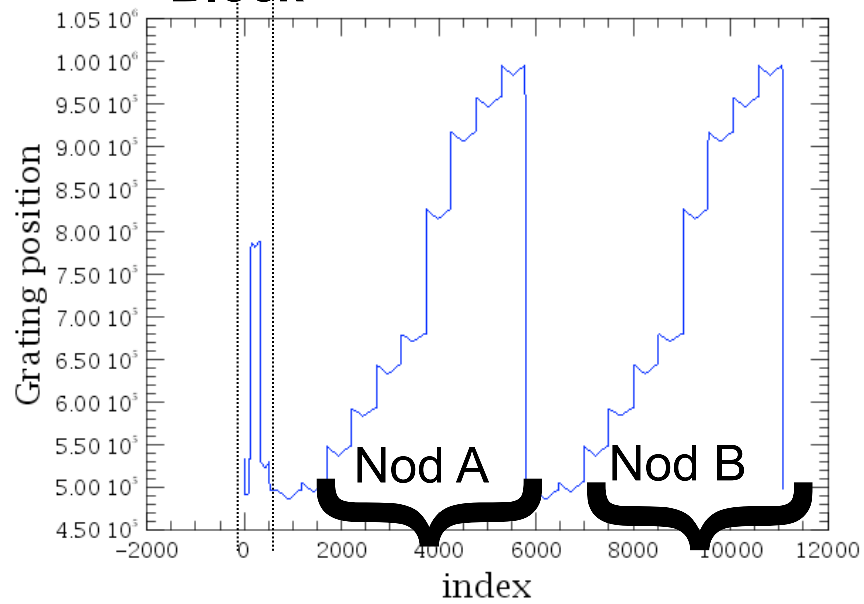
Signal=ramp's slope

Mechanisms

Internal Calibration Source 2 (CS2)

Internal Calibration Source 1 (CS1)

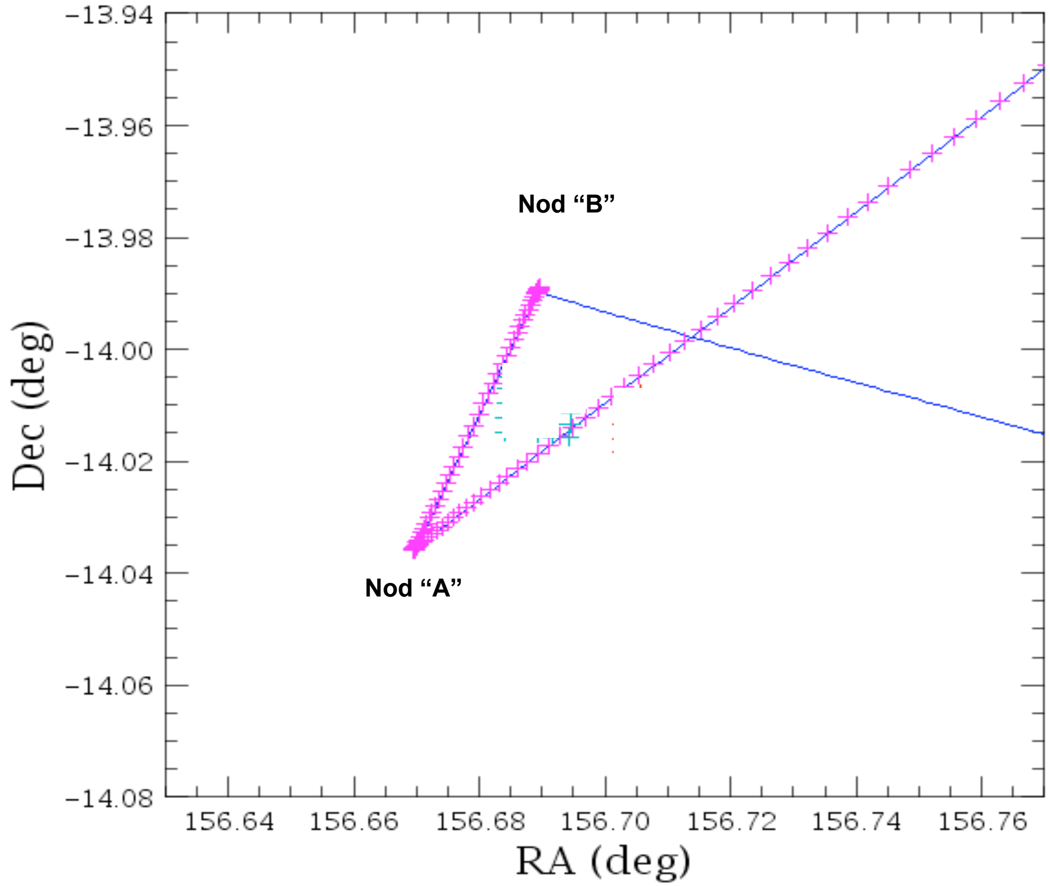




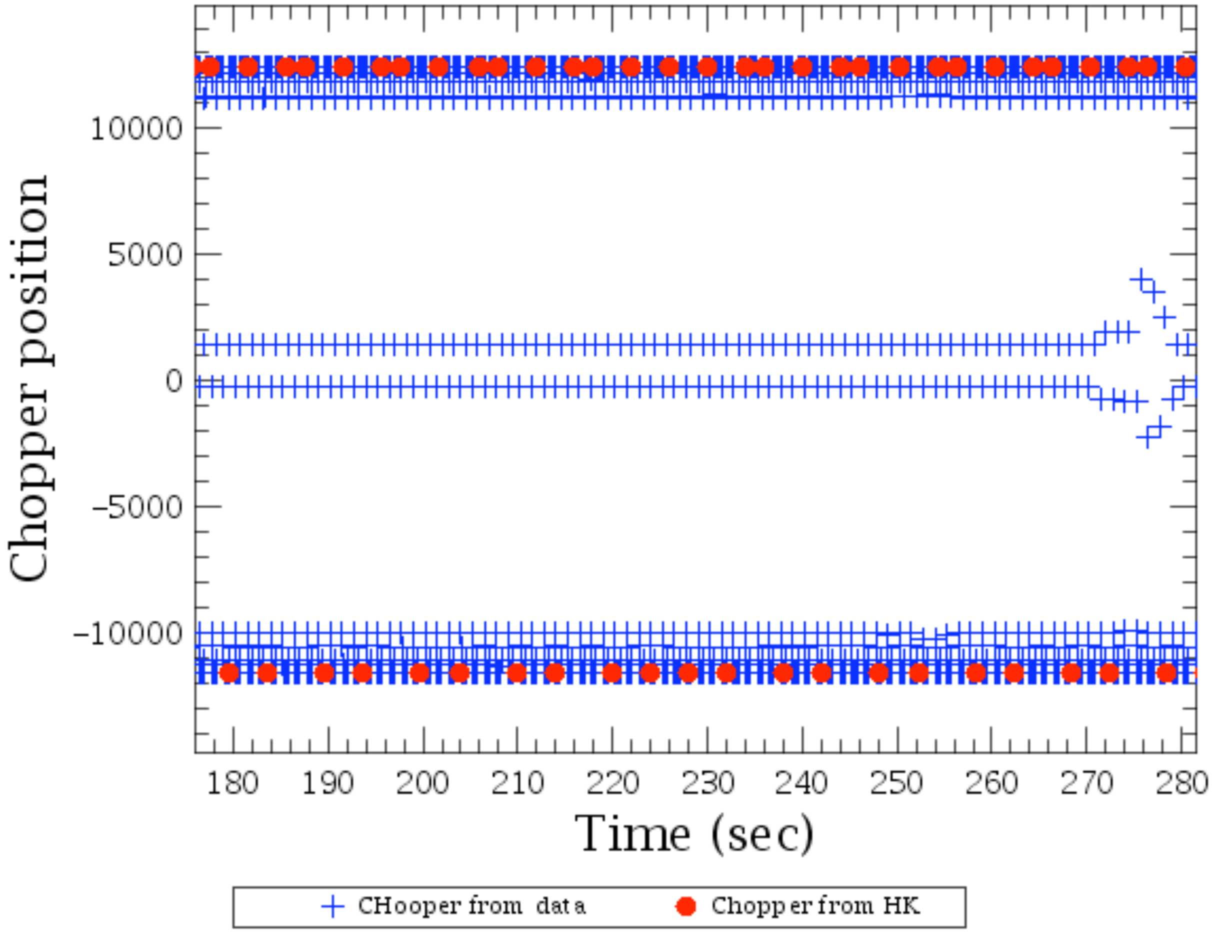
Grating

Pointing

Telescope boresight attitude info



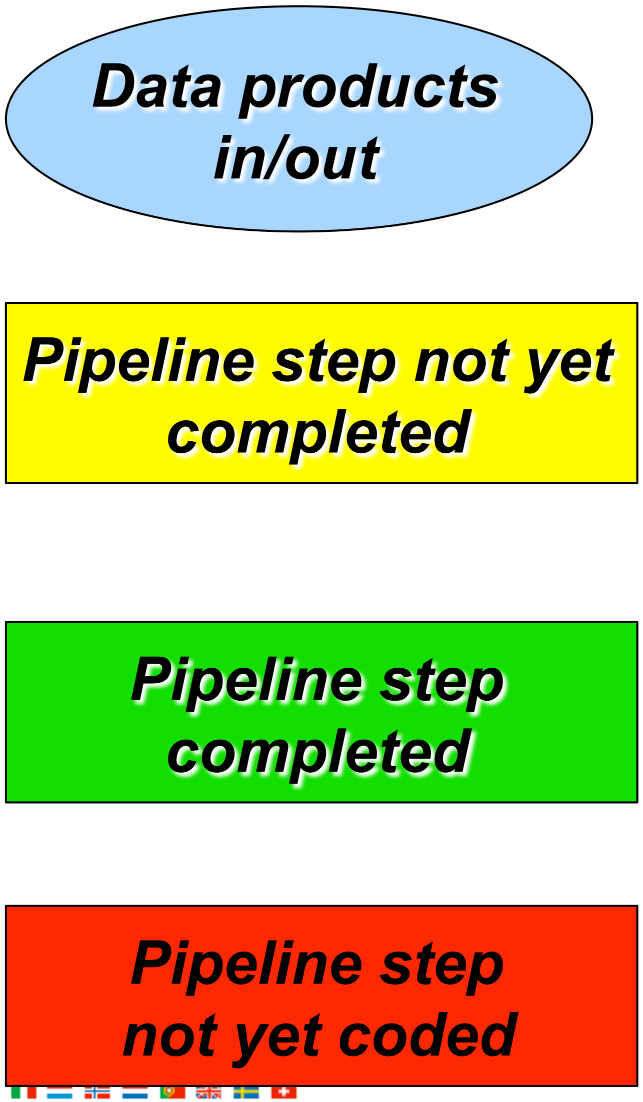
Housekeeping



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**
- **…**

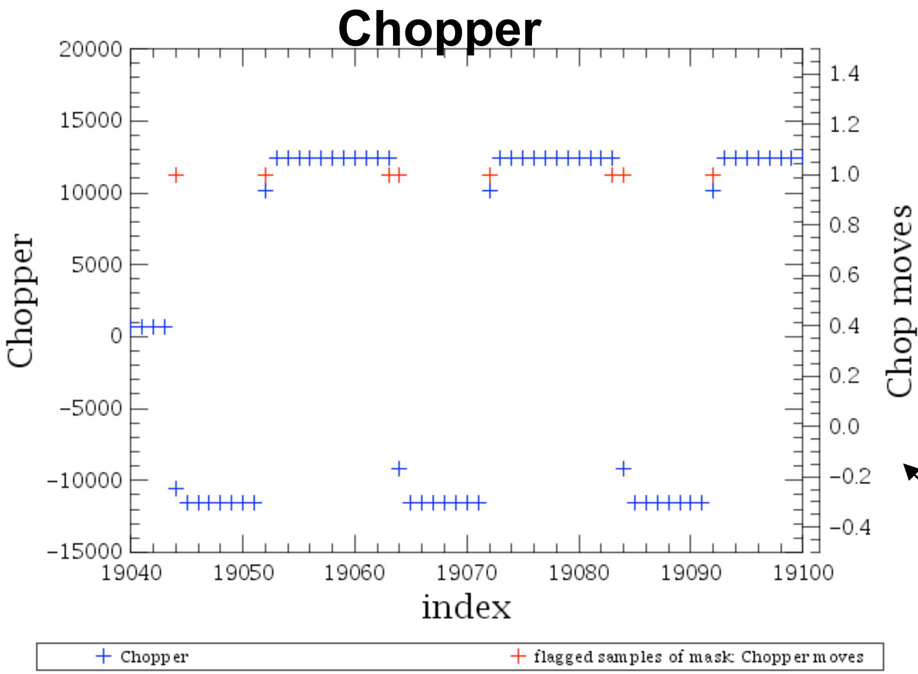
Color scheme for pipeline block diagrams

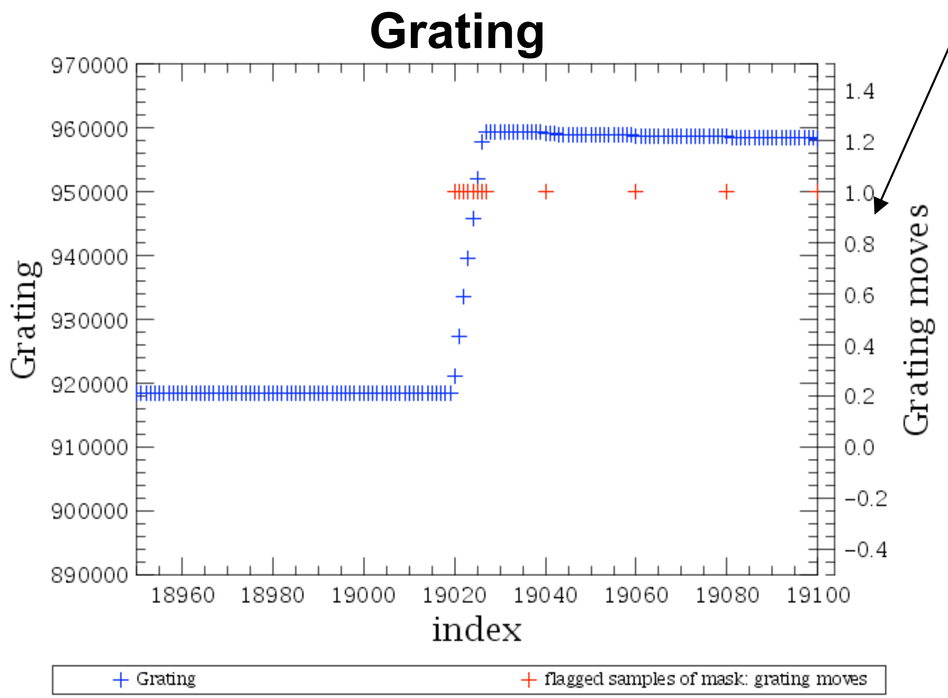


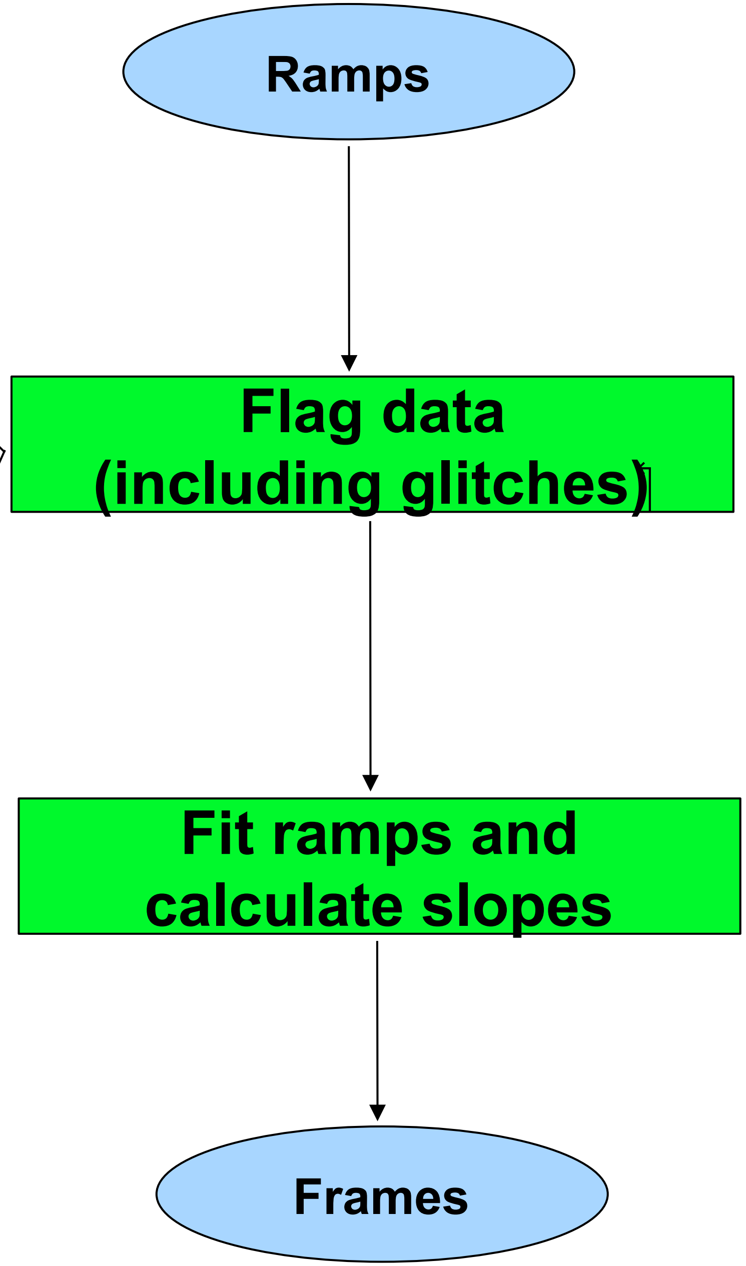
From Level 0 to 0.5

AOR independent

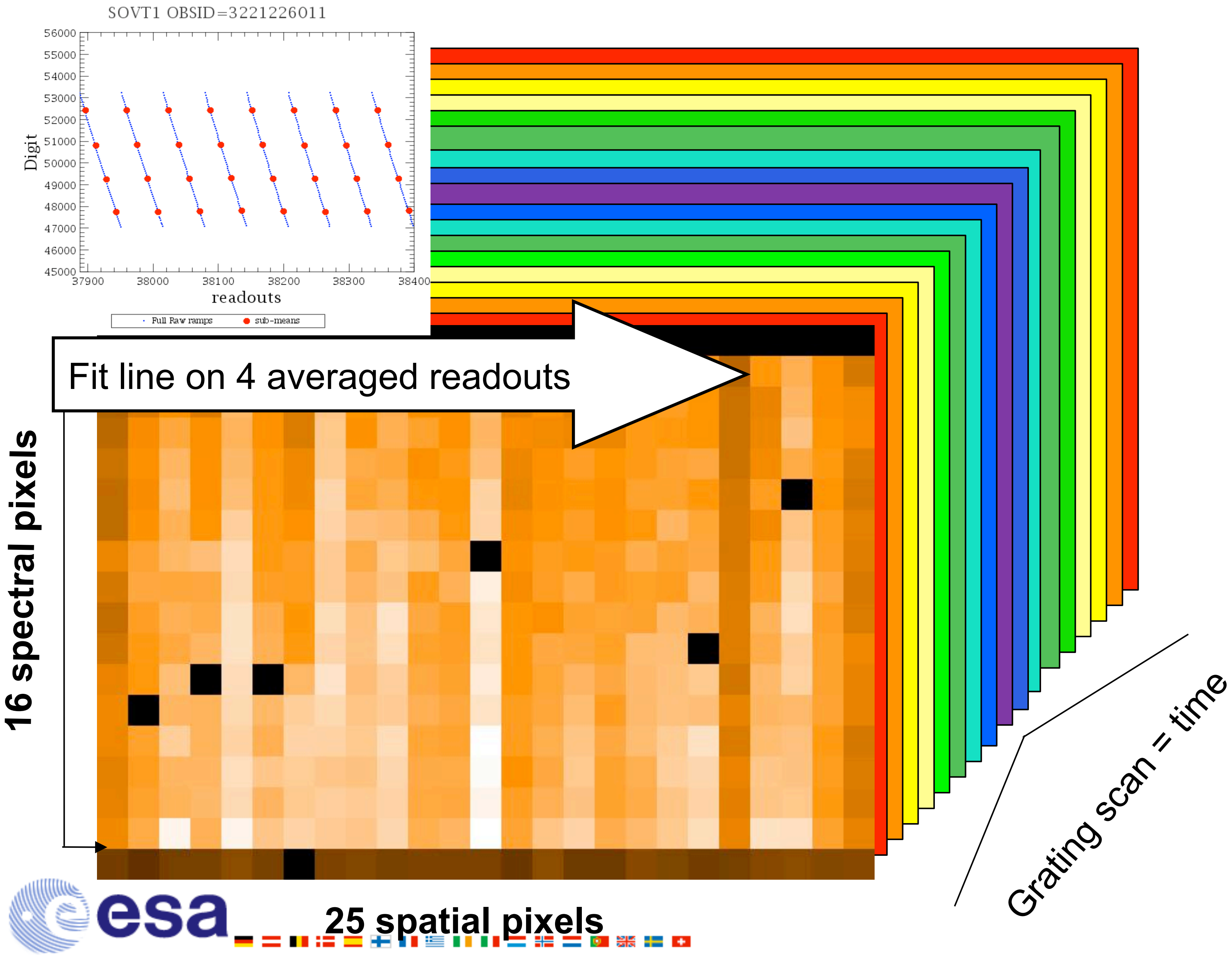
LEVEL 0


Chopper
20000
15000
10000
5000
0
−5000
−10000
−15000
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
19040
19050
19060
19070
19080
19090
19100
index
Chopper
Chop moves
Chopper
flagged samples of mask: Chopper moves

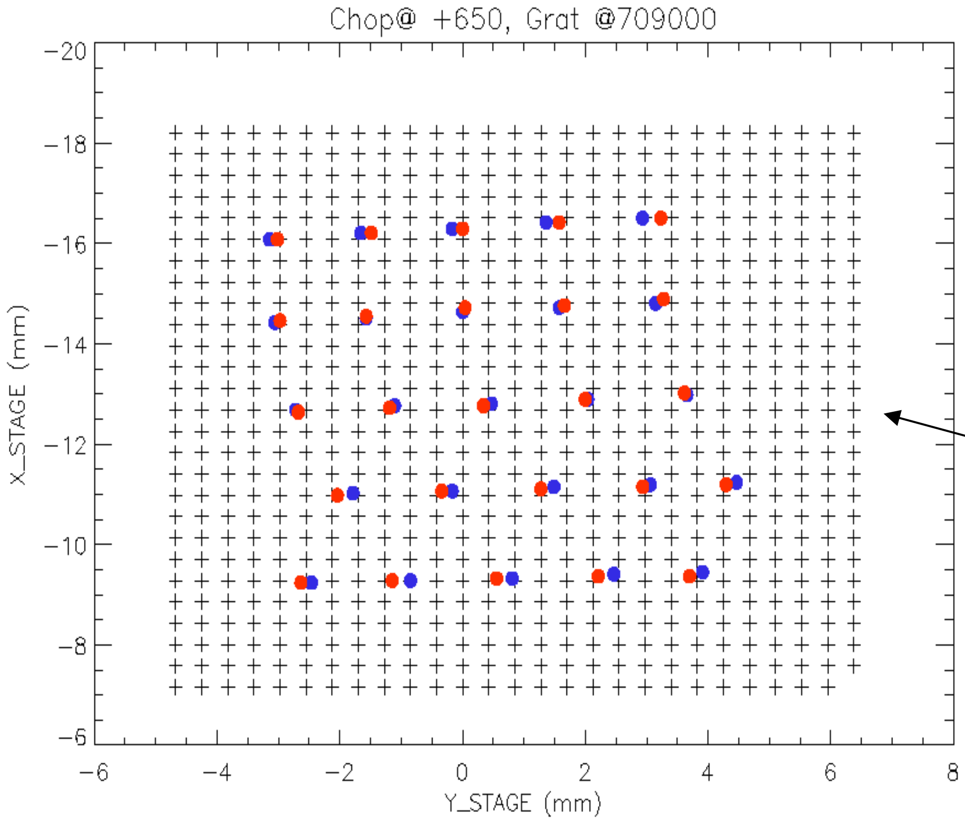

Grating
970000
960000
950000
940000
930000
920000
910000
900000
890000
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
18960
18980
19000
19020
19040
19060
19080
19100
index
Grating
Grating moves
Grating
flagged samples of mask: grating moves

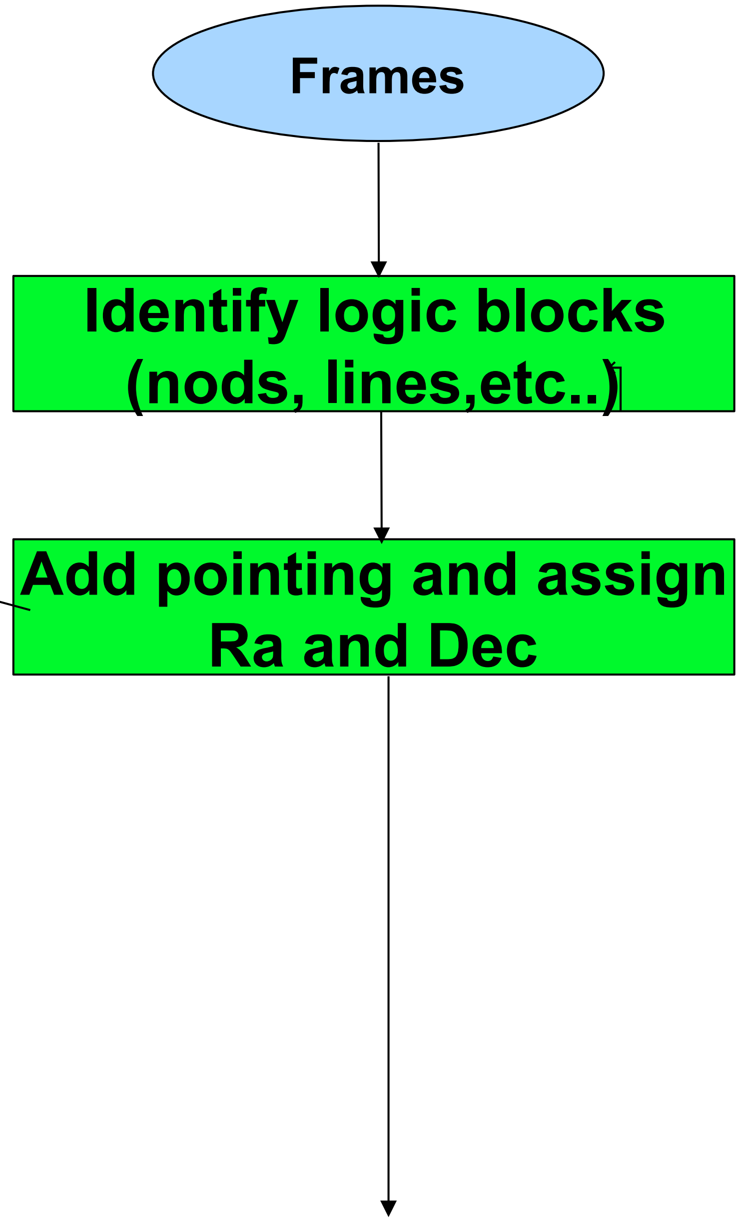

Ramps
Flag data
(including glitches)
Fit ramps and
calculate slopes
Frames

What do frames look like?

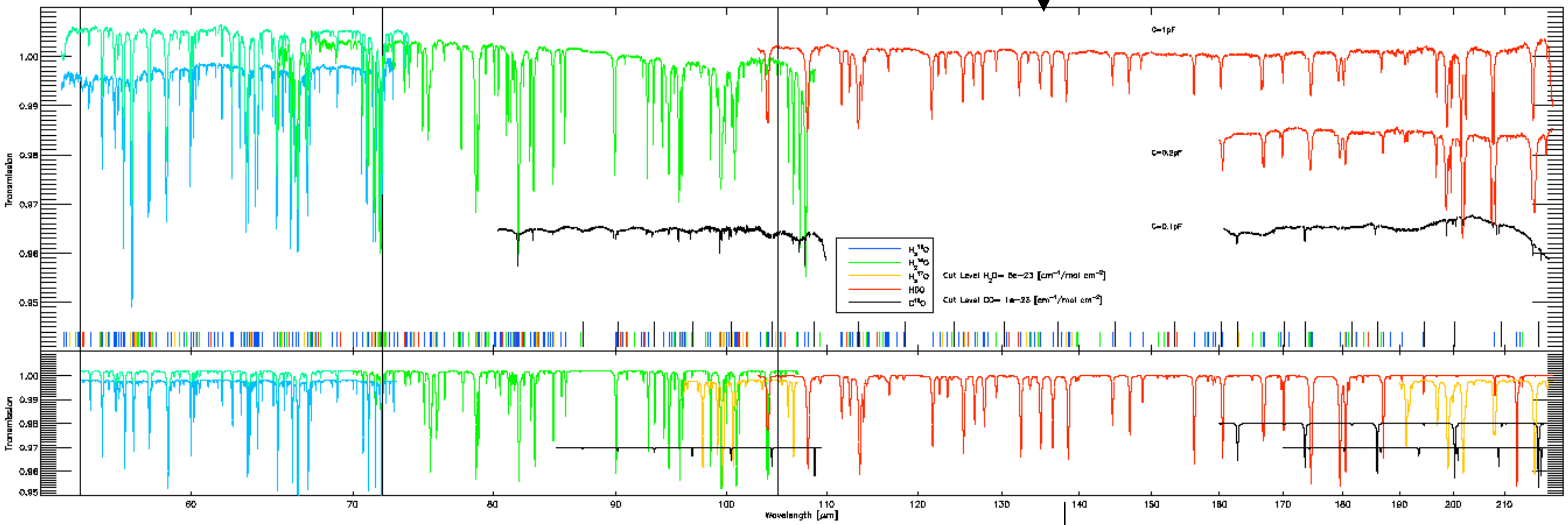


5x5 FOV





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

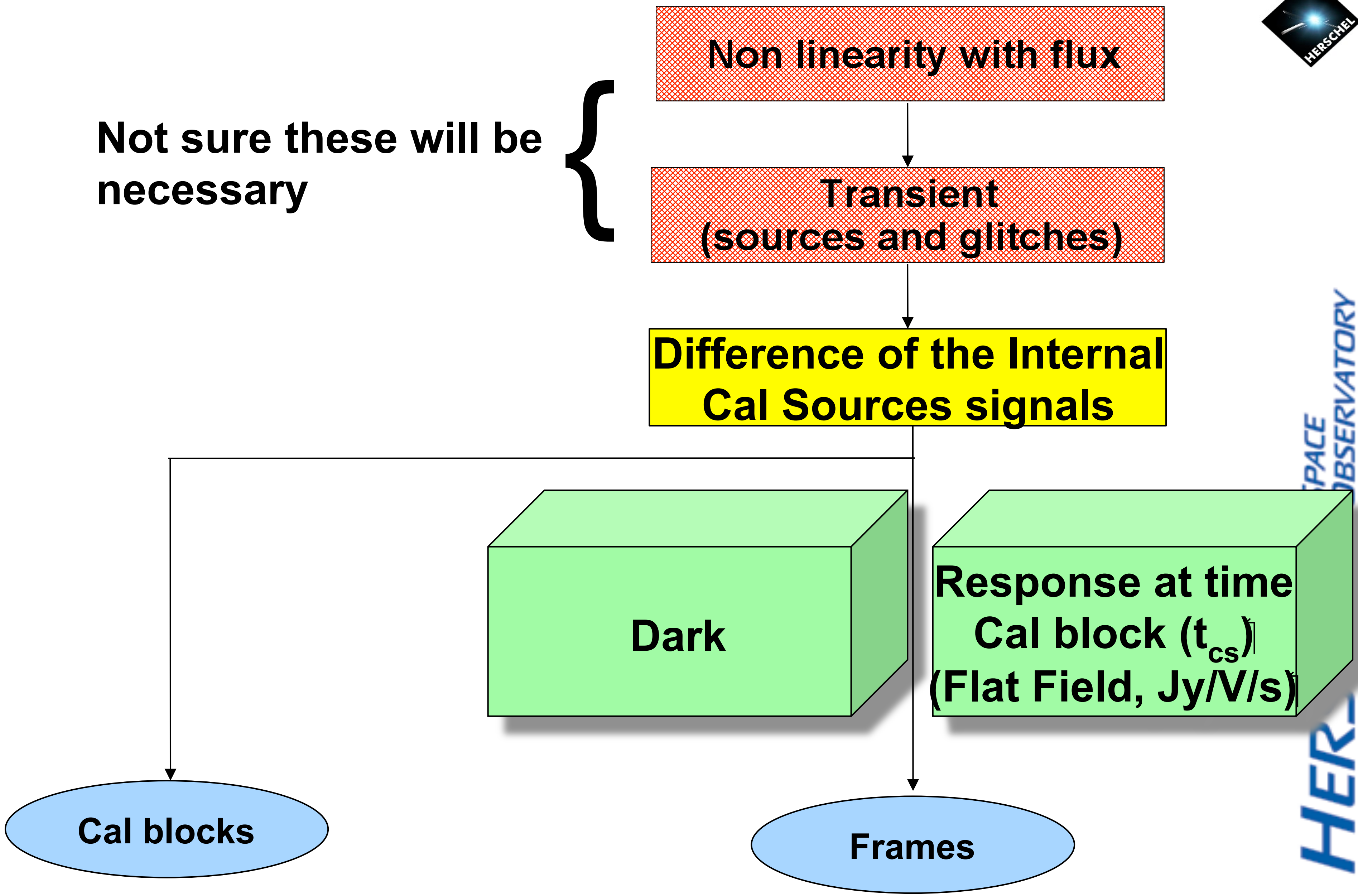


Assign wavelength to each pixel. Polynomial fit based on water cell wavelength spectrum observed in ground tests

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

From Level 0.5 to 1

AOR dependent !

Flux calibration concept for chopped obs.

- Difference of Internal Cal Sources signals gives Dark(pix,t) and $R(pix,t_{cs})$
- On-Off difference of the data nods A and B is:

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

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

Known from ground tests

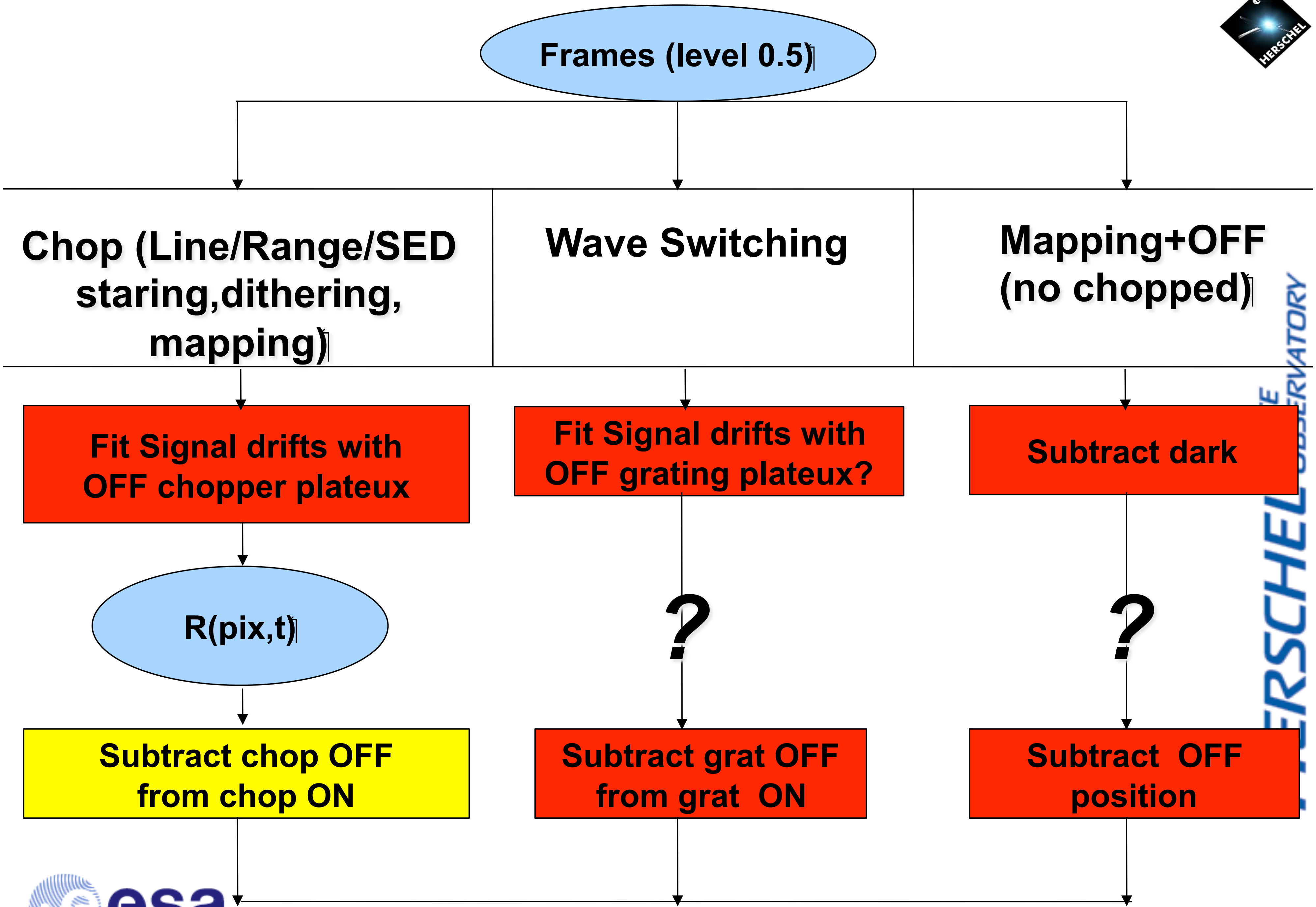
- $R(pix,t) \neq R(pix,t_{cs})$ due to glitches

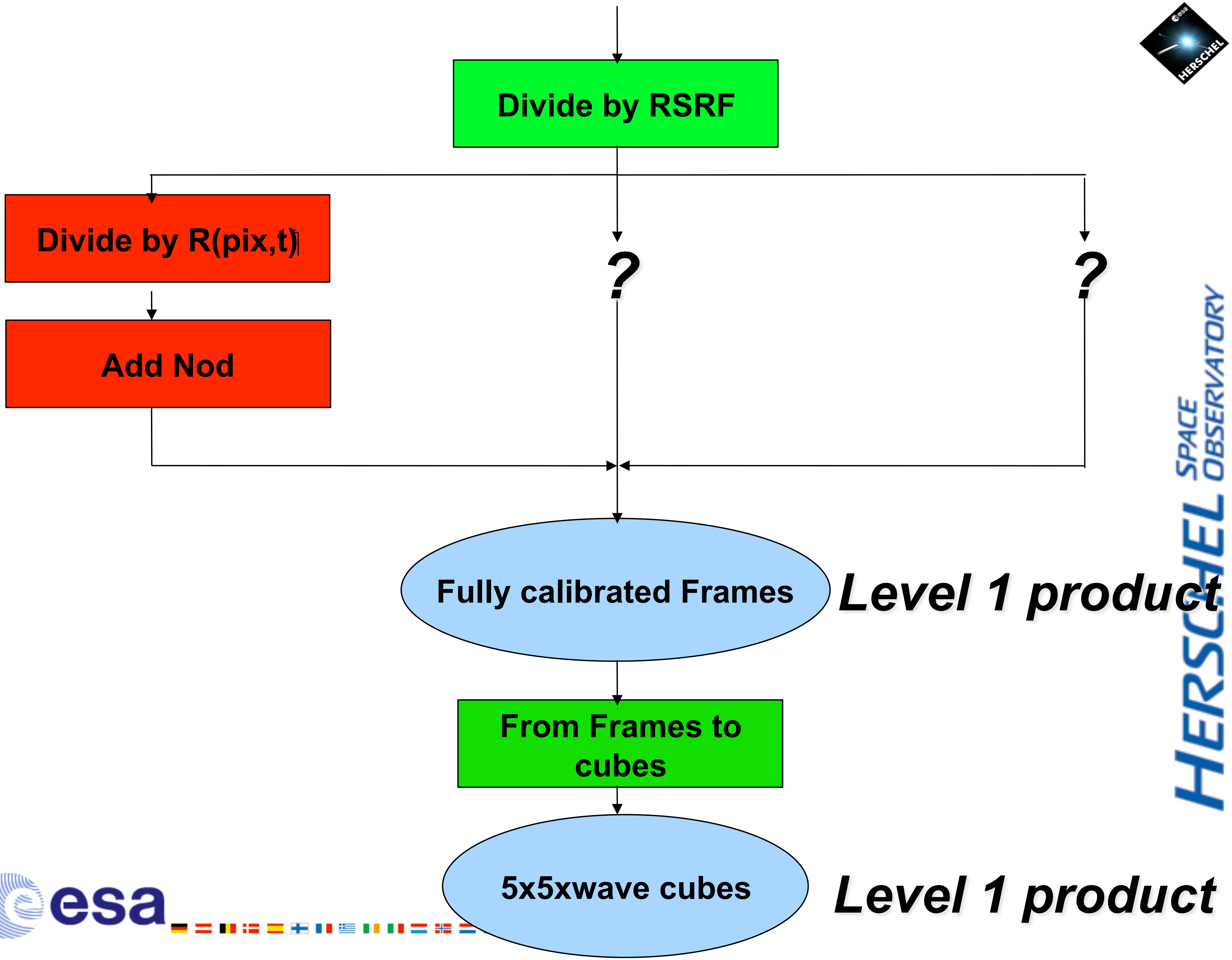
- R(pix,t) derived using the off plateaux signal and assuming that the telescope background spectrum as measured in the mean of all pixels is not affected by response drifts:

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

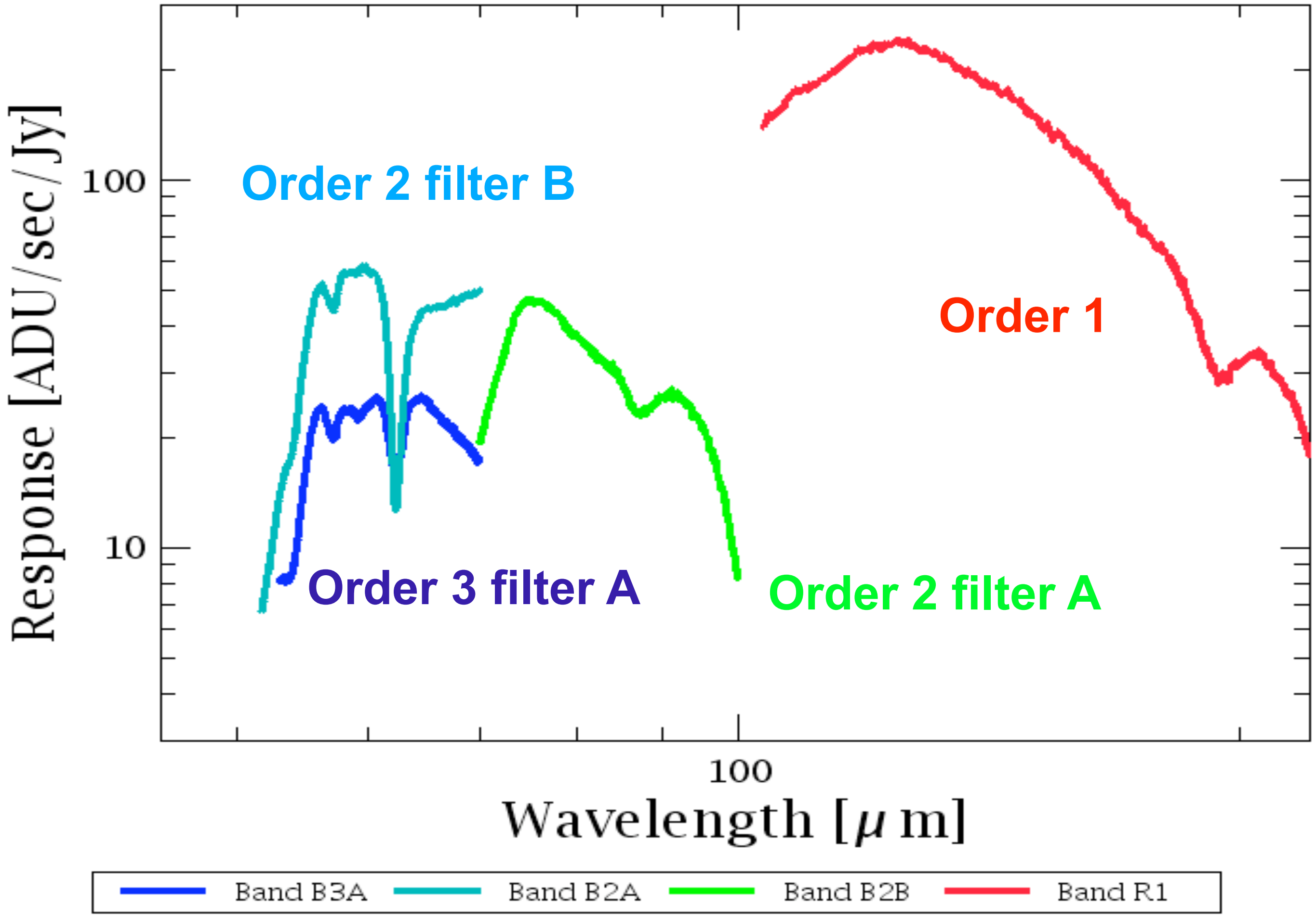
$$R(pix,t)=S_{off}/\left(\langle S_{sky}\rangle_{pix(i,j)} + \langle S_{T-}\rangle_{pix(i,j)}\right) \qquad \text{Nod A}$$

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


Frames (level 0.5)
Chop (Line/Range/SED staring,dithering, mapping)
Wave Switching
Mapping+OFF (no chopped)
Fit Signal drifts with OFF chopper plateux
Fit Signal drifts with OFF grating plateux?
Subtract dark
R(pix,t)
?
?
Subtract chop OFF from chop ON
Subtract grat OFF from grat ON
Subtract OFF position


Divide by RSRF
Divide by R(pix,t)
?
?
Add Nod
Fully calibrated Frames
Level 1 product
From Frames to cubes
5x5xwave cubes
Level 1 product

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

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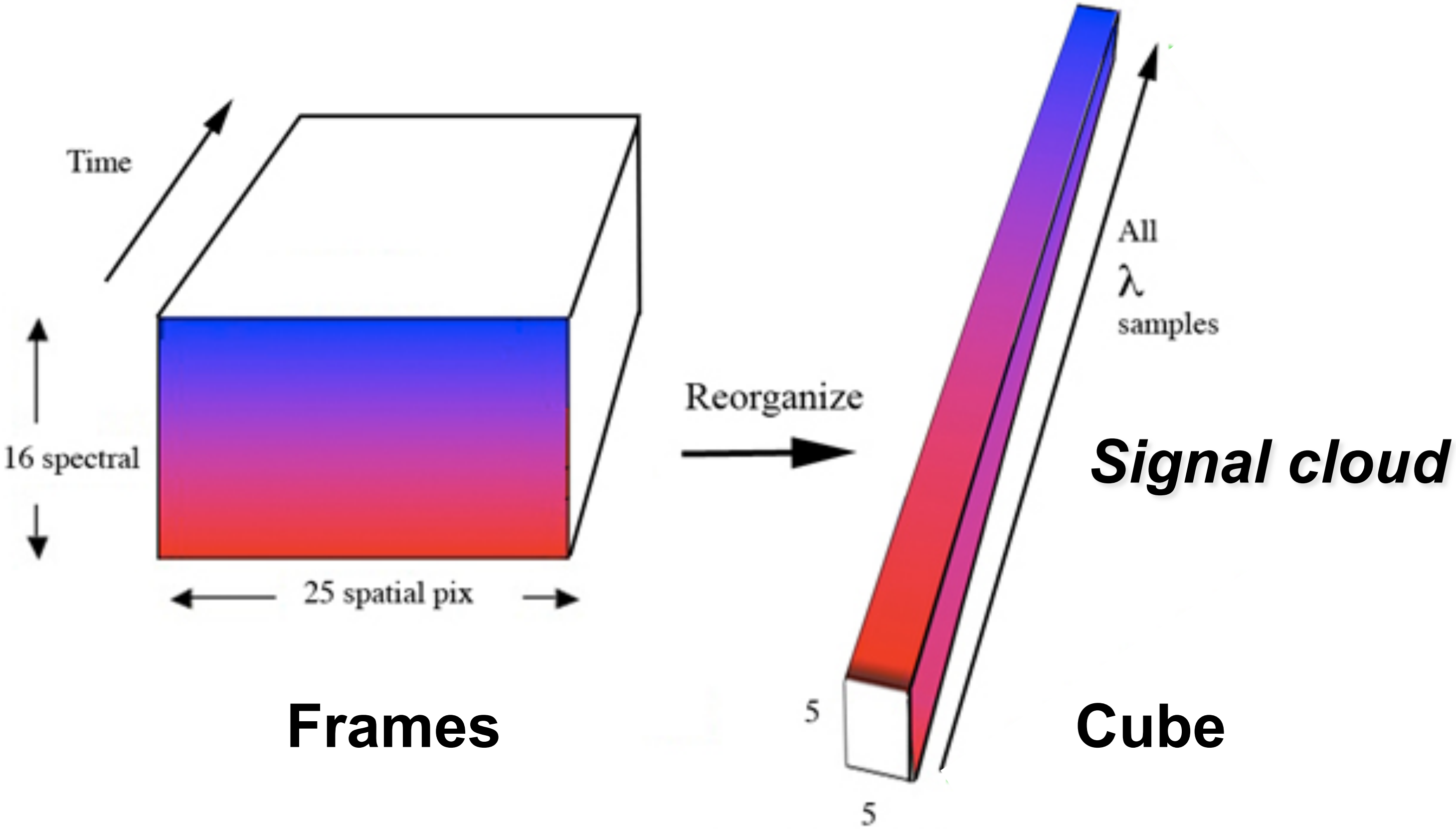
2 Level 1 products! Same thing but different organization



Frames

Cube

25x16xN → 5x5xNX16

From Level 1 to 2

Where user interaction becomes important

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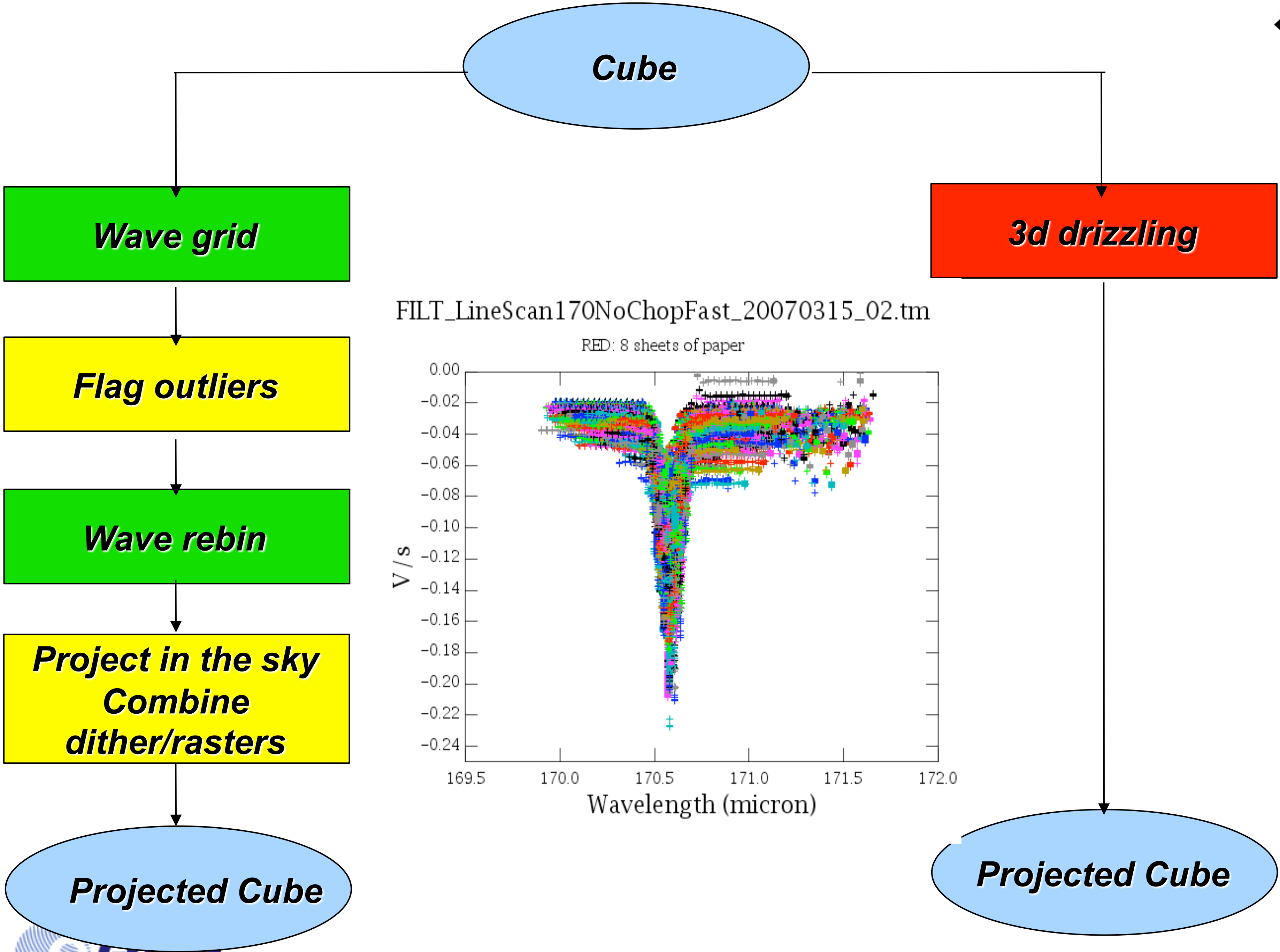
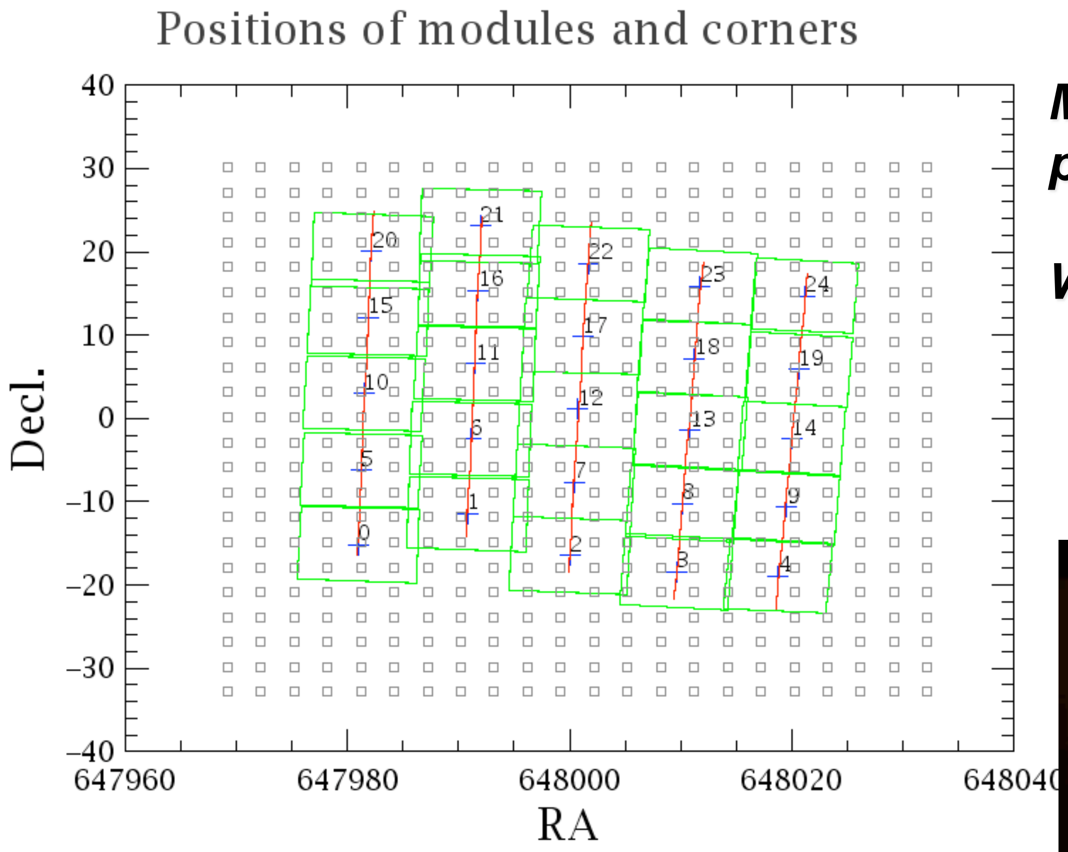
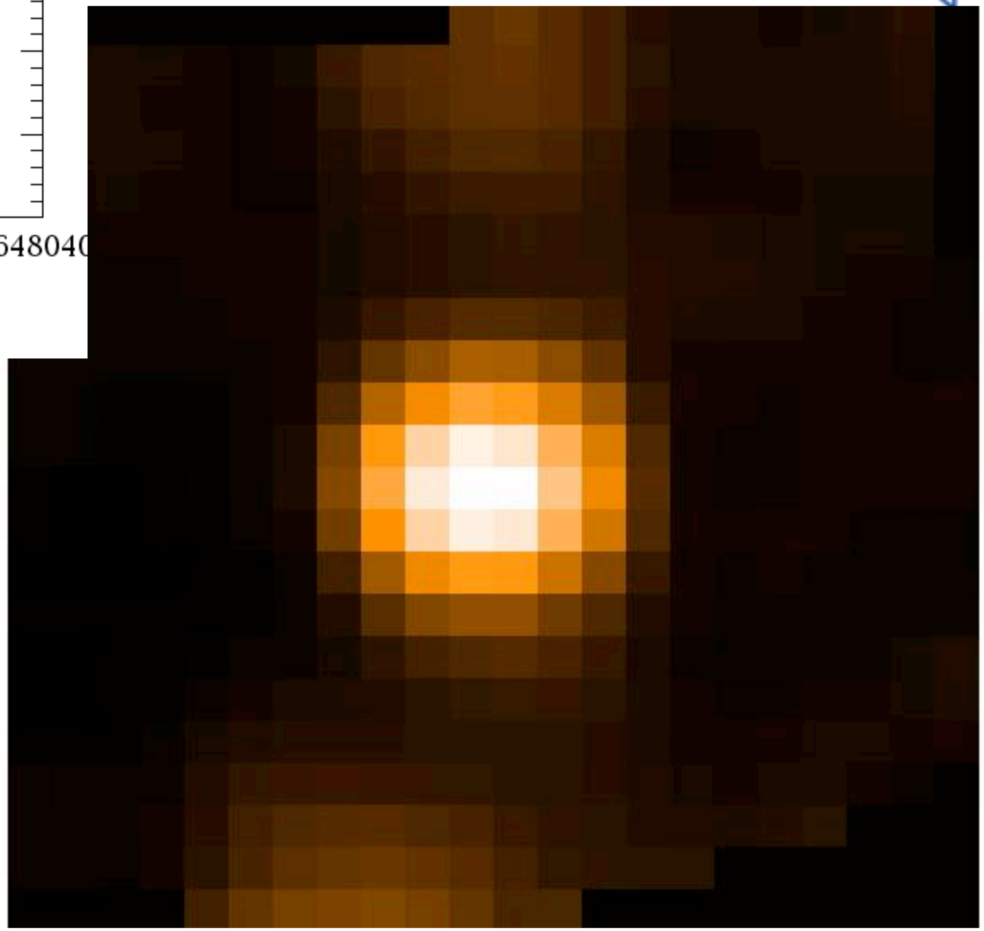

Cube
Wave grid
Flag outliers
Wave rebin
Project in the sky
Combine
dither/rasters
Projected Cube
3d drizzling
Projected Cube
FILT_LineScan170NoChopFast_20070315_02.tm
RED: 8 sheets of paper
V/s
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
-0.16
-0.18
-0.20
-0.22
-0.24
169.5
170.0
170.5
171.0
171.5
172.0
Wavelength (micron)



Messy spatial FOV; pixels not physically squared.

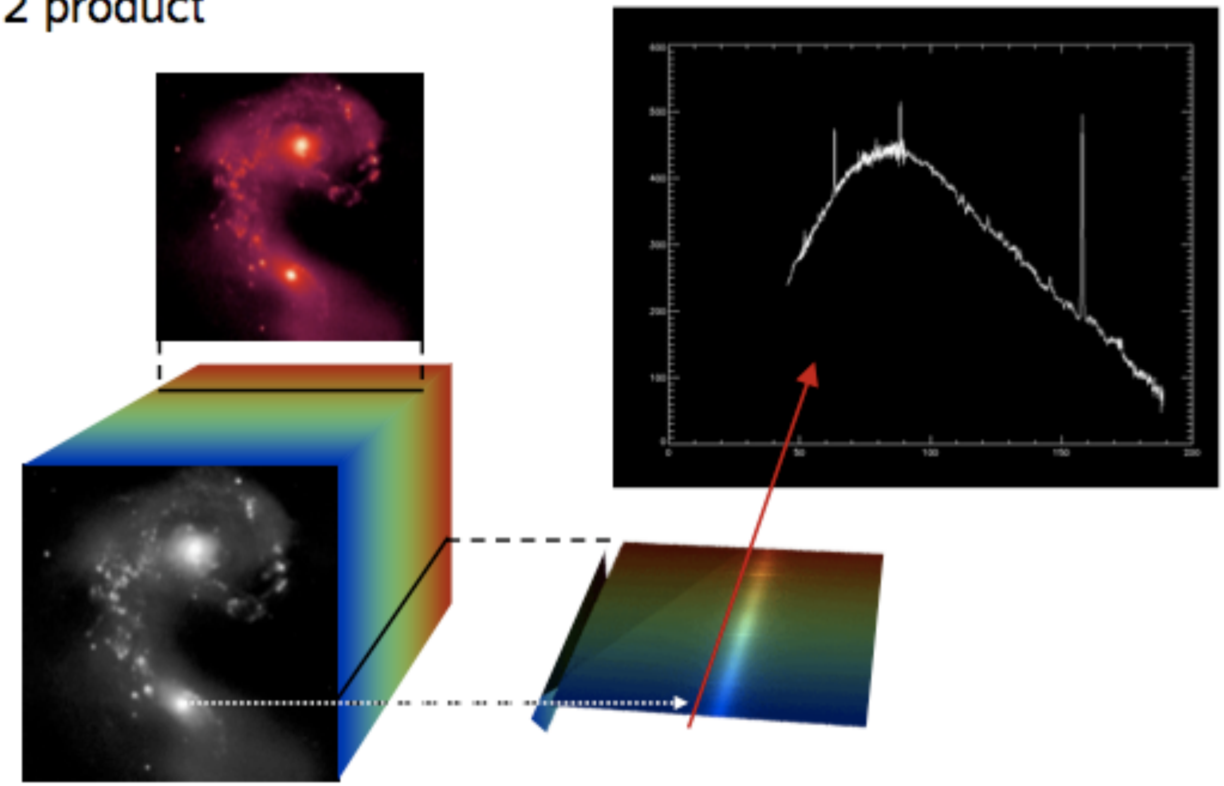
We have to regrid onto a regular grid



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

Rebinned cube and projected cube – Level 2

Level 2 product



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

See A. Gueguen and S. Regibo demos

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.

PACS Spectroscopy pipeline documentation

Detailed presentations of the December workshop:

http://herschel.esac.esa.int/DP_workshop.shtml

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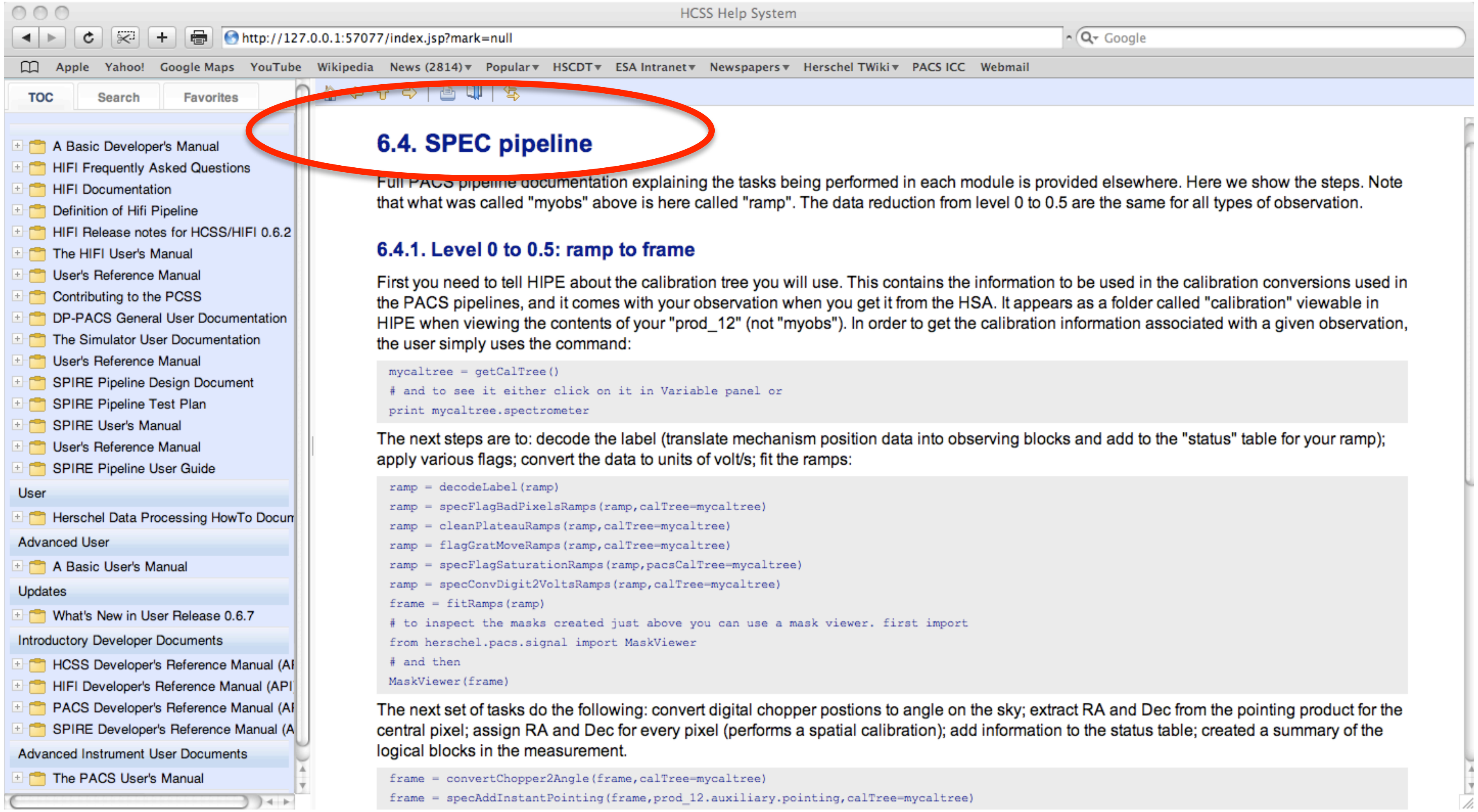
PACS Spectroscopy pipeline documentation in HIPE: short HowTo



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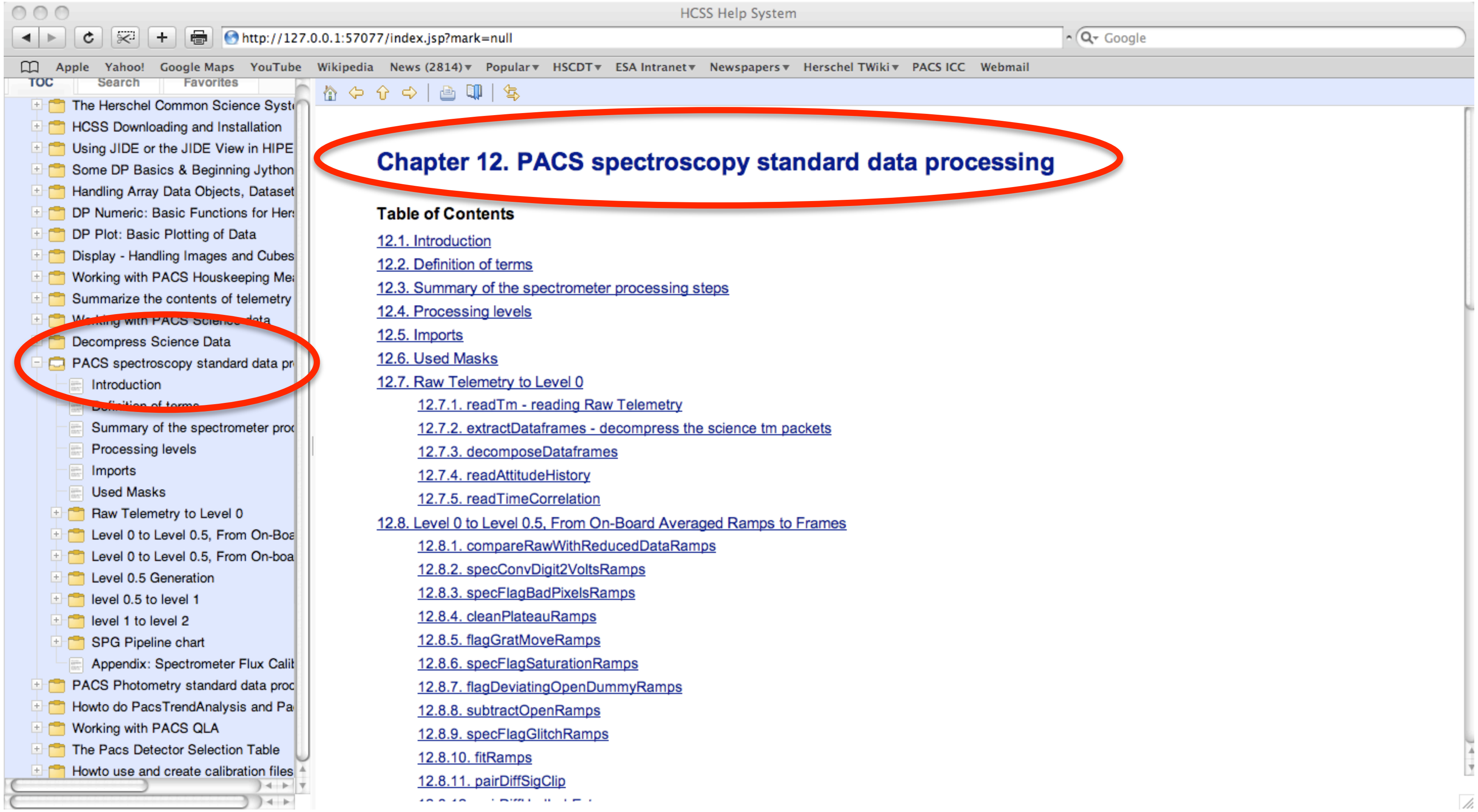
PACS Spectroscopy pipeline documentation in HIPE: SPG description in PACS User's Manual



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Hands-on session:
Run the pipeline

Before starting the hands-on session

- ***Be sure you have installed***
  - ✓ HIPE 0.6.7.1 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 cretate a Local Store of Observation Context for OBSID 3221226016:

~/.hcss/lstore/demo2LocalStore_pacsSpectroChopNod_24032009

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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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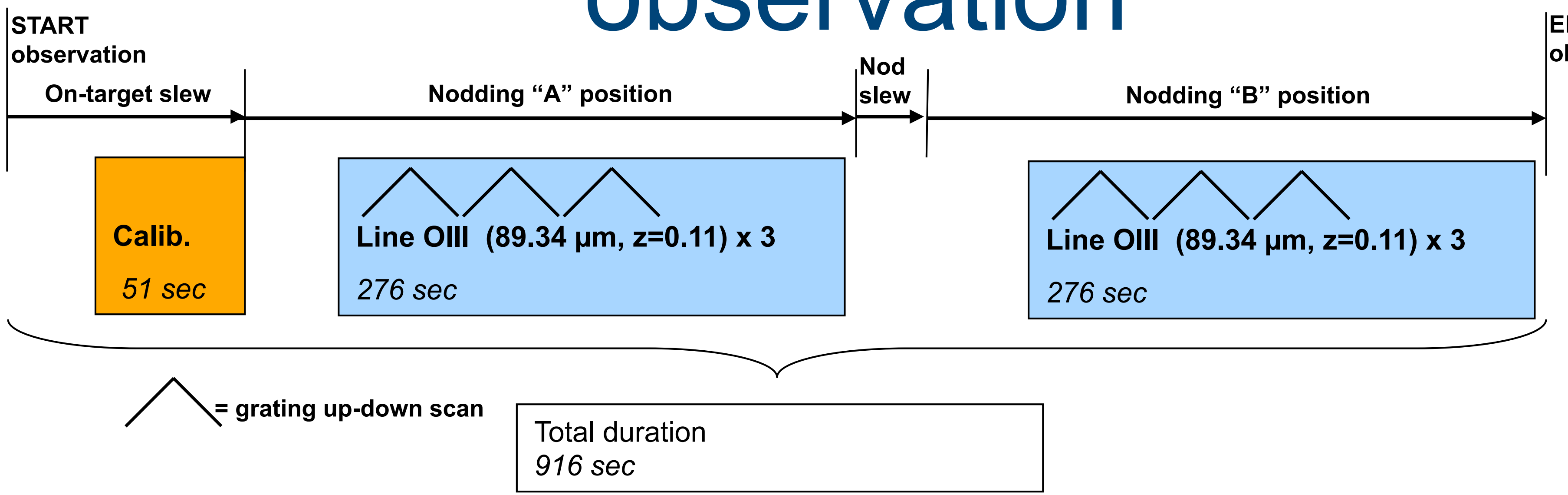
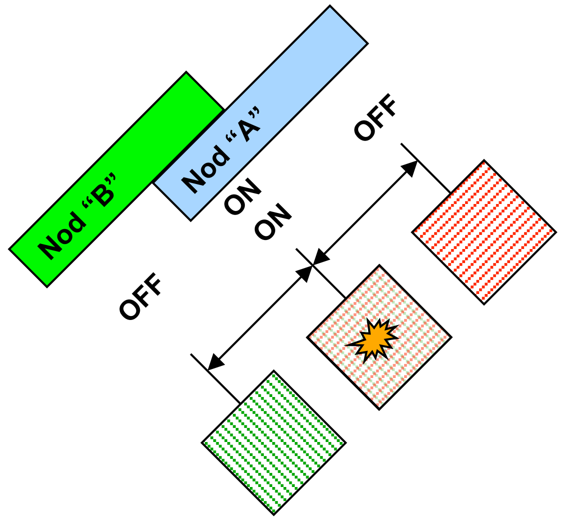
AOT blocks of the demo observation





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

HERSCHEL SPACE OBSERVATORY

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]