SPIRE photometer pipelines

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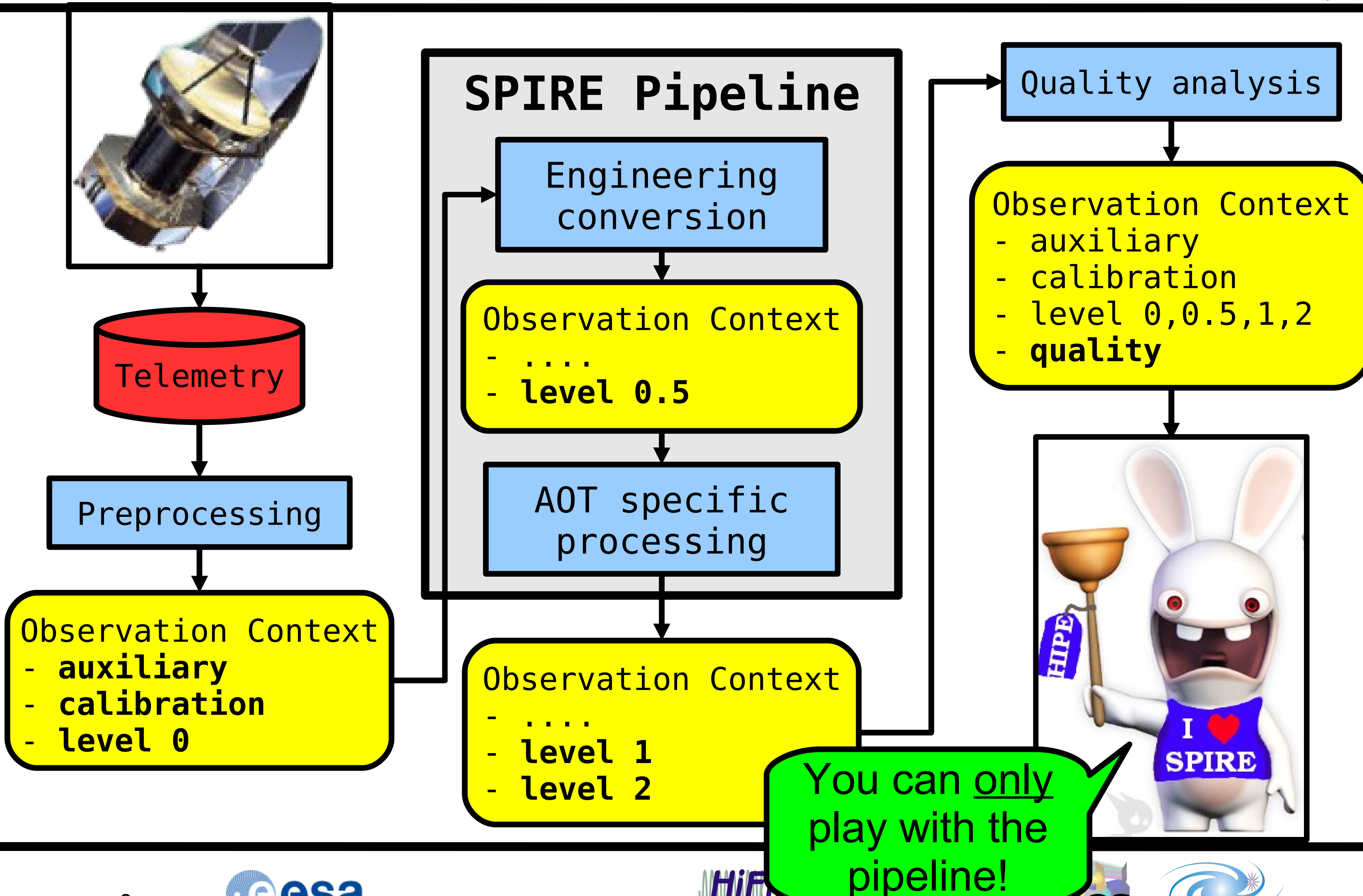
SPIRE Pipelines status

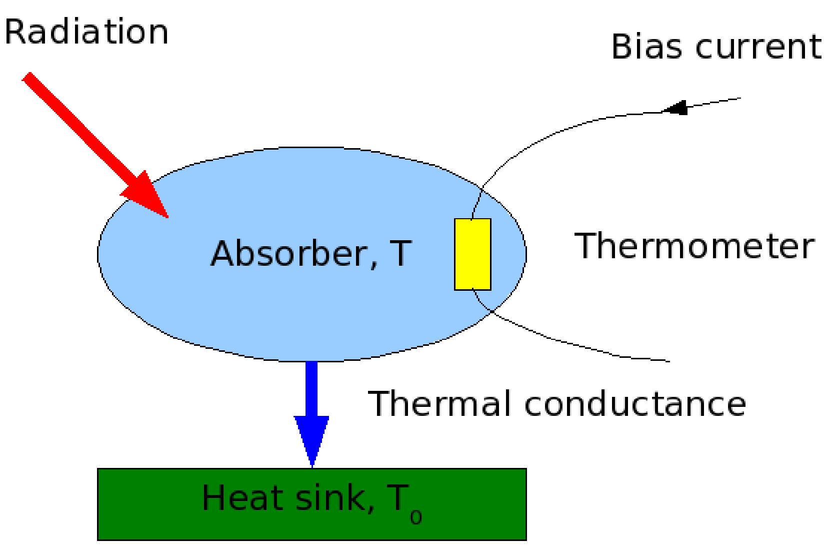
- Almost all tasks written and implemented in the pipelines!
  - All pipelines arrive to level 2 products
- Functionalities and documentation are under review and all pipeline modules are under systematic testing as part of an ongoing Science Validation process
  - Although pipelines are quite advanced, do **not** assume that they are **final**
- Issues requiring attention:
  - Calibration files to be update after launch (PV phase)
  - AOTs could be changed during PV phase
  - Moving coordinate frames for targets with large motion
  - Ensure that tasks and pipelines are user-friendly for IA

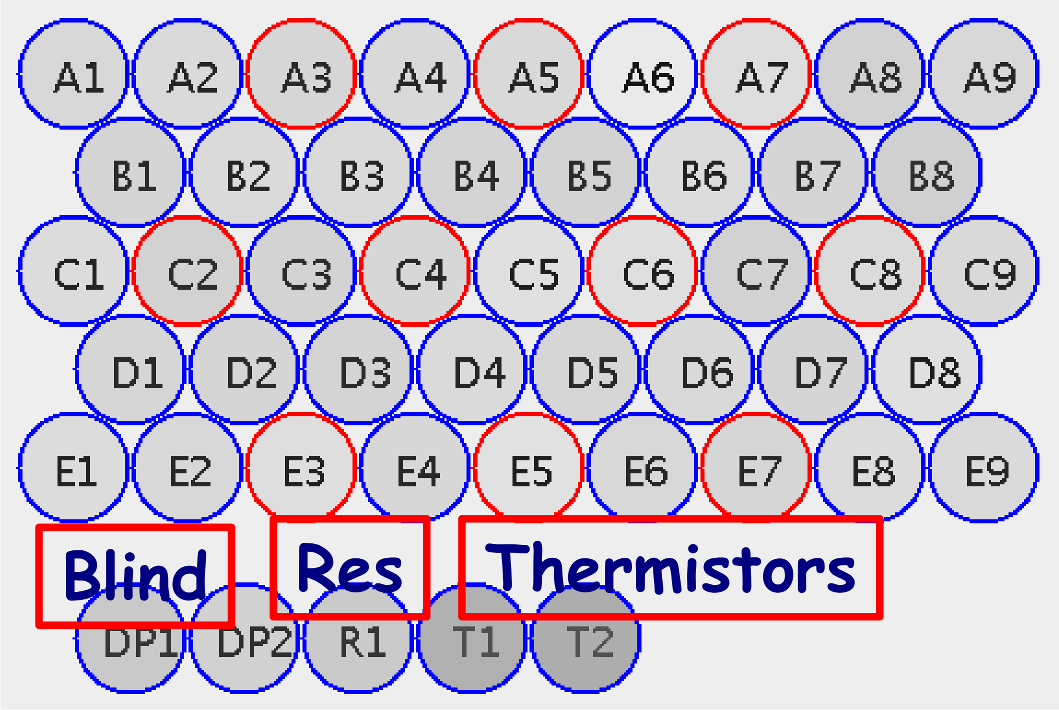
SPIRE global data flow



SPIRE detectors

- SPIRE detectors are basically resistors whose **resistance** is dependent on the **temperature**. The temperature correspondingly depends on the **flux**.

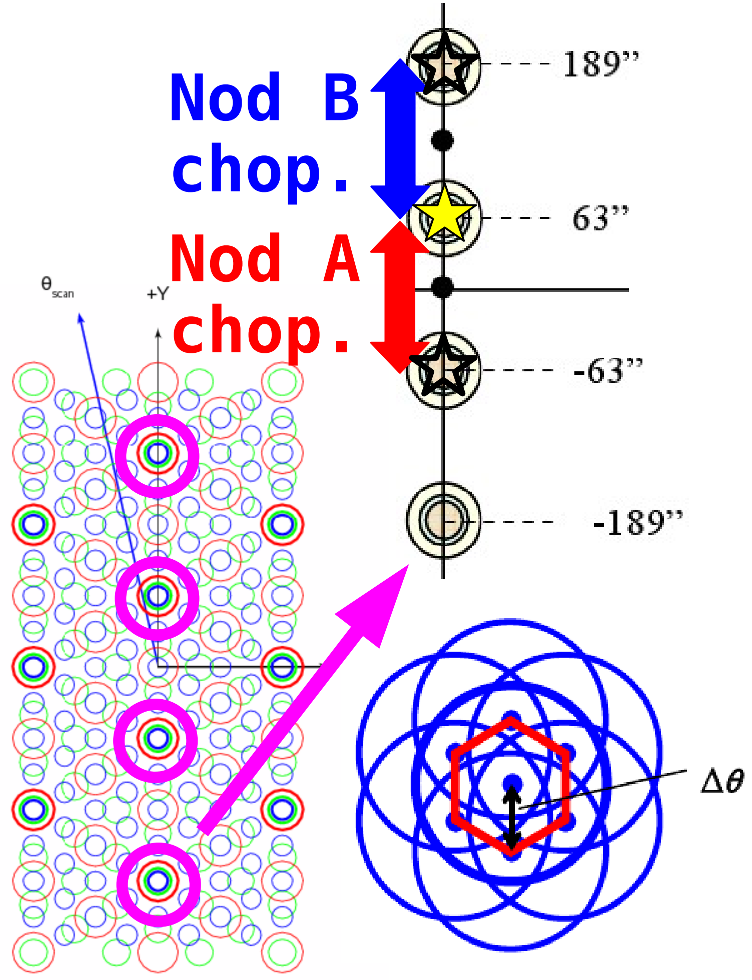




- Each array SPIRE has 2 **blind** detectors, 2 **thermistors** and 1 **resistor**

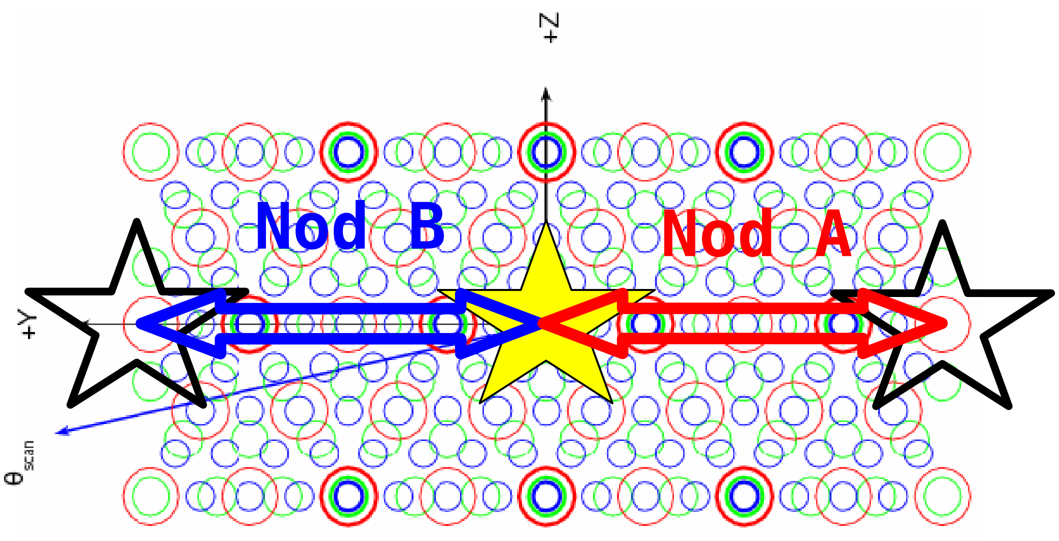
Point Source Observing Mode

- Optimized for compact sources
- The instrument chops by ±63" with the BSM to remove background (sky and telescope).
- The telescope performs one or more **ABBA** nodding sequences to remove asymmetries in optics and in telescope background
- A 7-point mini-map (ΔΘ=6", i.e. 1/3 of PSW detector beam) is made with the BSM to ensure that the source signal and position can be estimated

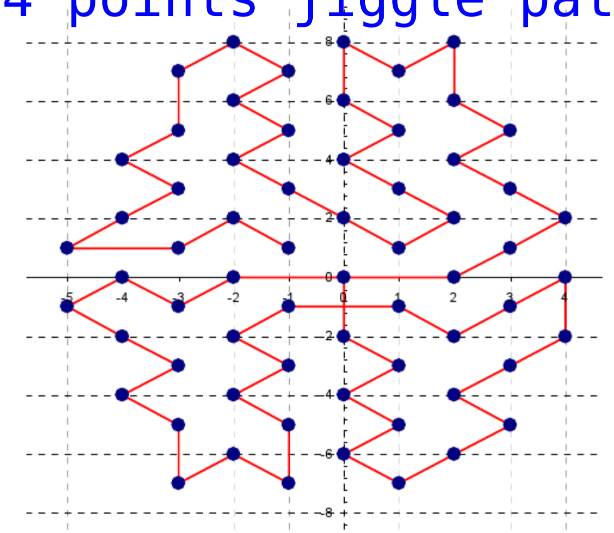


Small Map Observing Mode

- Optimized for imaging of a small (4'x4') field
- 64 jiggle positions are made to create a fully sampled map
- 4 **AB** nodding sequences with 16 jiggle positions each.
- Chopper throw is ±126"

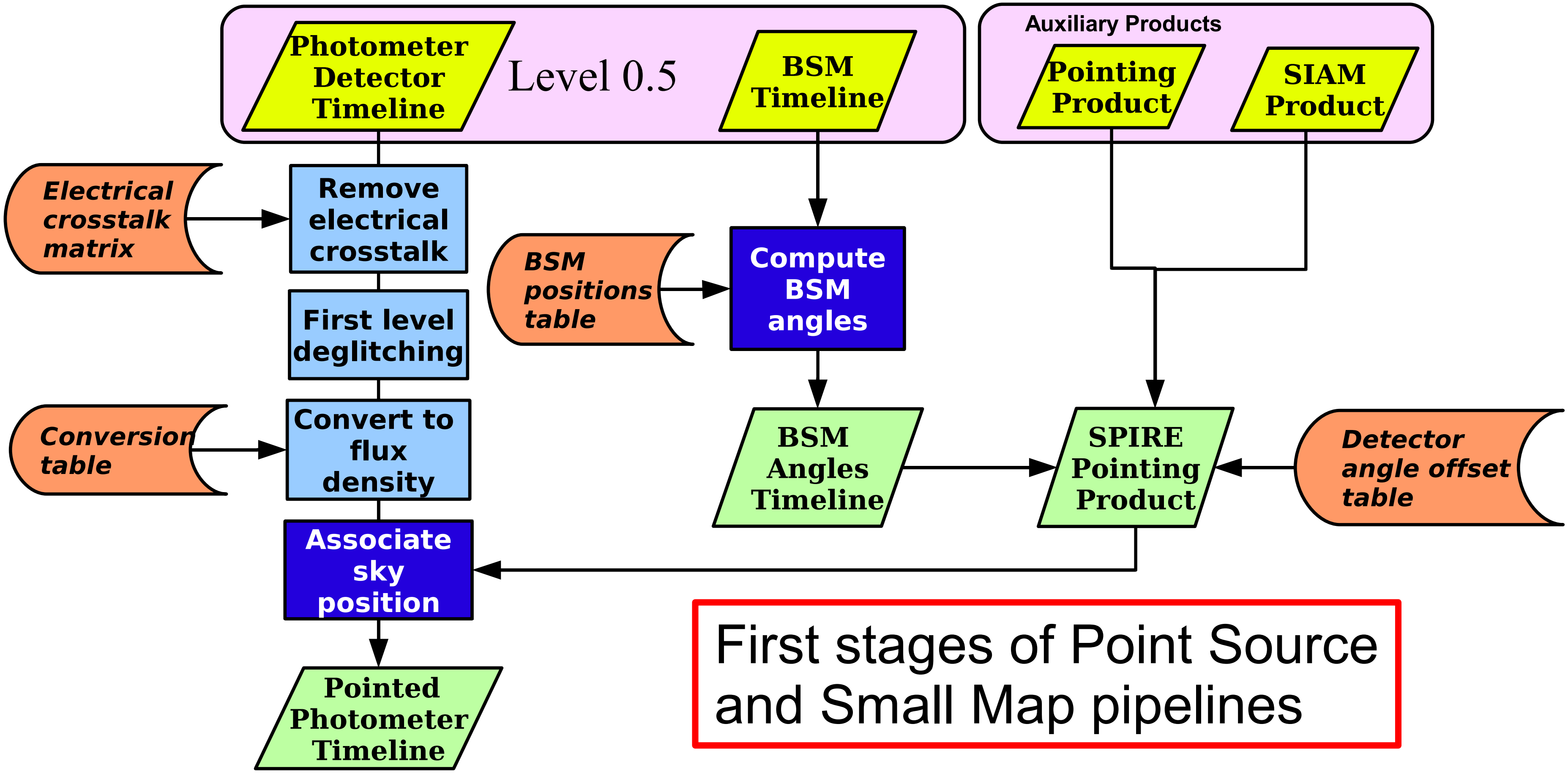


64 points jiggle path



Point Source & Small Map pipeline

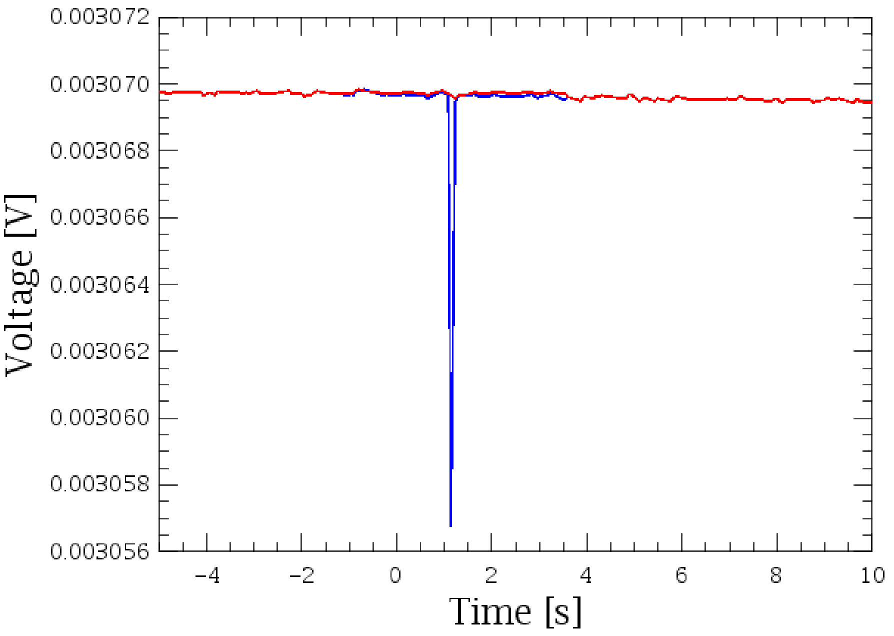
- Photometer Detector timeline contains voltages and resistances of each bolometer as function of time.



First stages of Point Source and Small Map pipelines

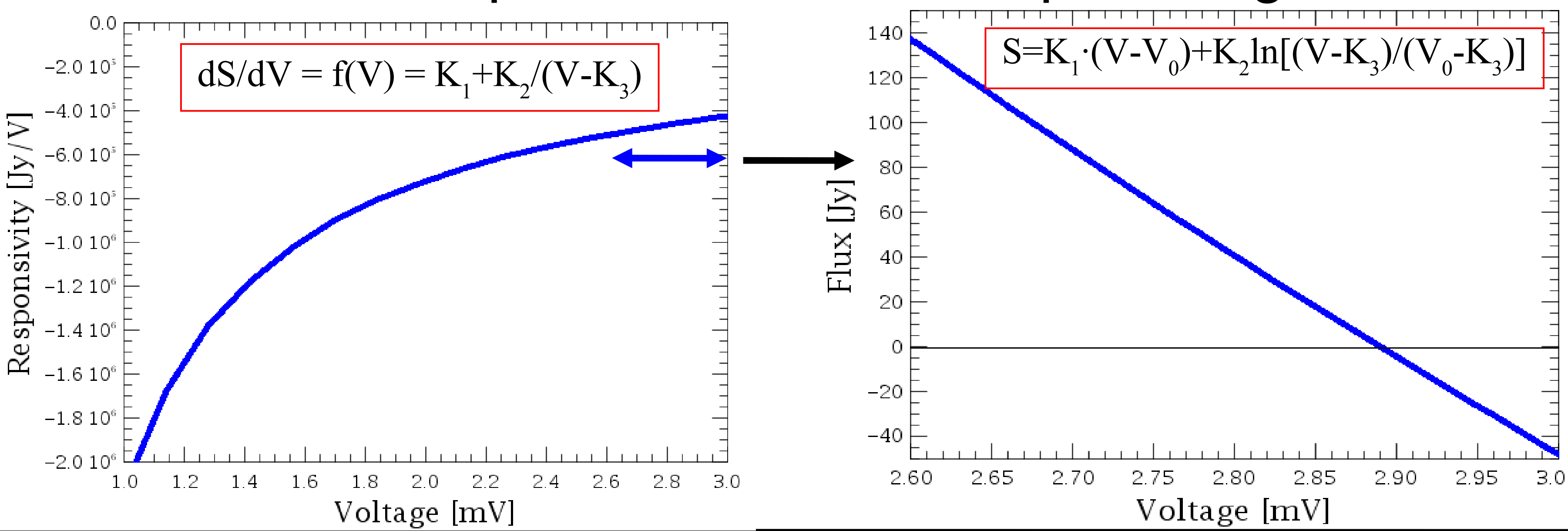
First level deglitching

- Effects are rather simple
  - No change in responsivity
- Deglitching algorithm is based on regularity & wavelets analysis
- Same algorithm used in spectrometer and photometer pipelines
- Glitches are identified and removed
- Using wavelets, this method is also possible on modulated data
- Signal reconstruction not yet optimized



Photometer Flux Conversion

- Responsivity dS/dV calculated with a bolometer model
  - Good fit with an analytical function $f(V, K_1, K_2, K_3)$
  - Integrating f(V) gives the flux, S
- Constants V_0, K_1, K_2 & K_3 contained in calibration product
- Note: the constants K_1, K_2 & K_3 depend on bias voltage, V_0 also on bath temperature and telescope background.

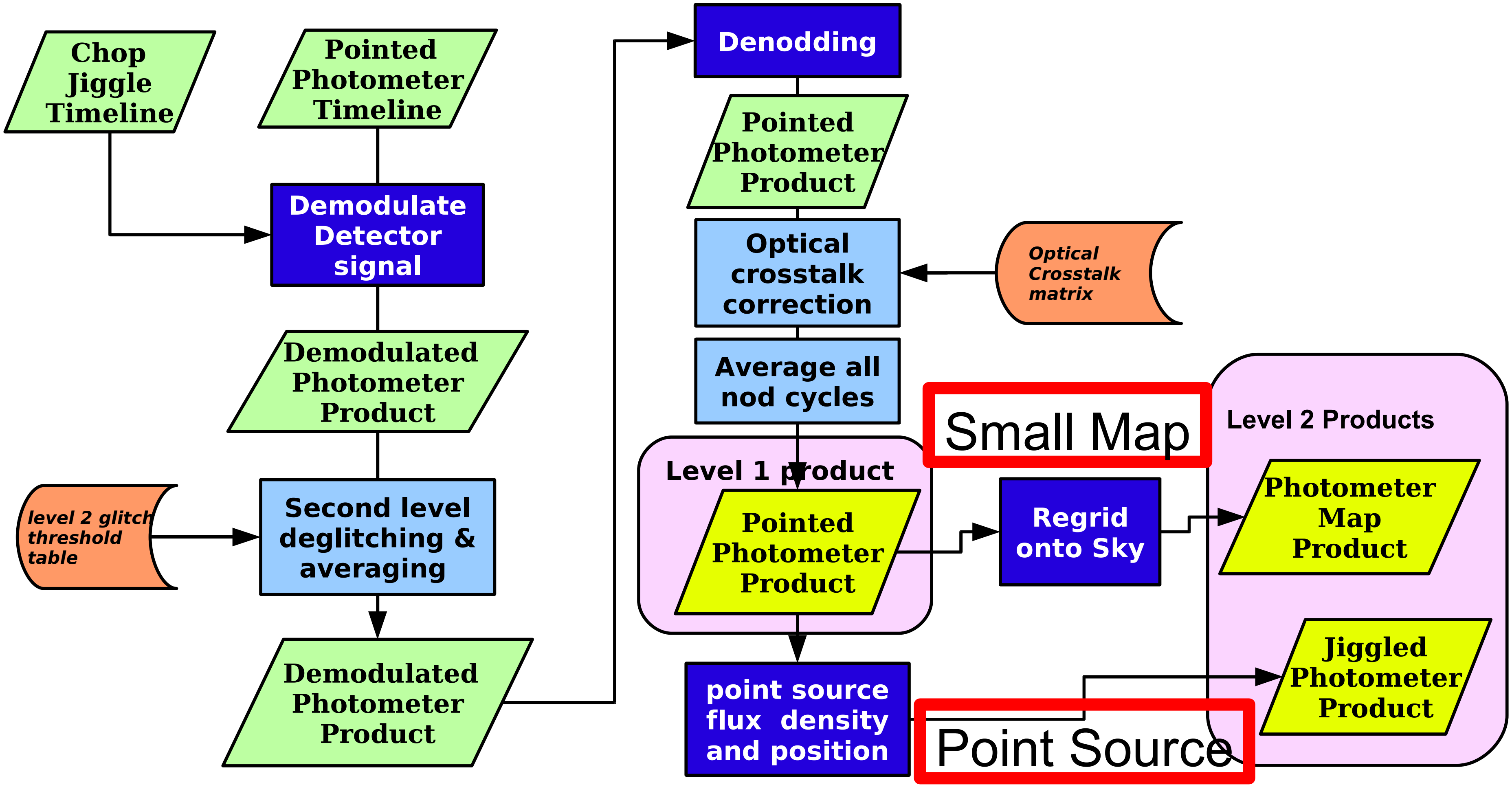


Associate Sky Positions

- To know the position in sky where each detector is looking, we need:
  - The Herschel Pointing Product
  - The SIAM Product
    - position of SPIRE reference aperture w.r.t. spacecraft pointing
  - The Detector Angular Offset
    - Detector positions with respect to the SPIRE reference aperture
  - The BSM Angle Timeline
    - Positional shift introduced by the Beam Steering Mirror
- For each time sample, the RA & Dec of each detector is computed
  - Two additional tables, **`ra`** and **`dec`**, are attached to the timelines

Point Source & Small Map pipeline

- Second stage flowchart

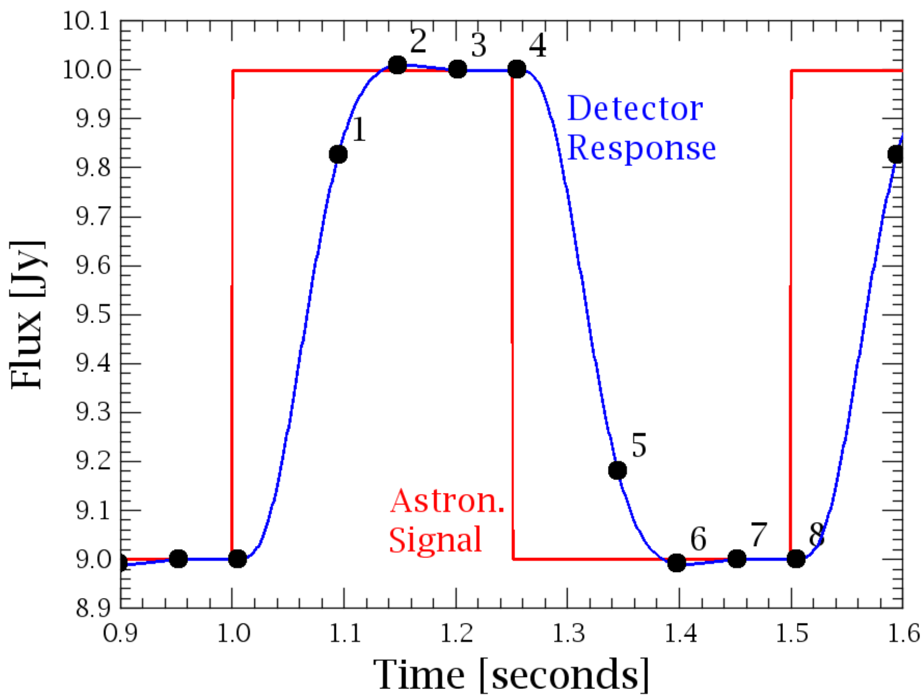


Demodulation

- The instrument chops to remove the background, so we must demodulate
- 4 detector samples are taken per chopper position
  - sampling not regular in time
- Demodulation follows a simple approach:

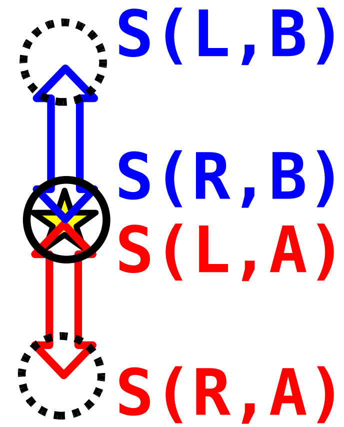
  $S_k=[(s_2+s_3+s_4)-(s_6+s_7+s_8)]/3$
- Fitting detector response with a model is under study

- One flux value per chop cycle
  - Several cycles per jiggle position → S_k with $k=1...N_{chop}$



Jiggle averaging & Denodding

- Demodulation will give $S_{k,j}$ = S(L) - S(R) for each chop cycle *k* and jiggle position *j*
- 2nd level deglitching flags outliers
- Jiggle Averaging on chop cycles
  - $S_j=(\Sigma_k S_{k,j})/N_{chop}$

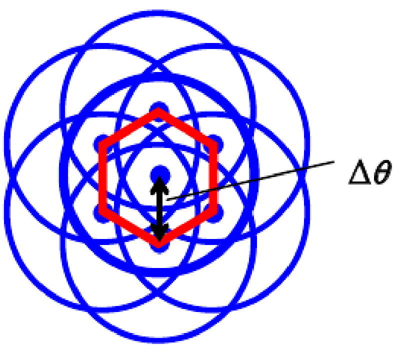


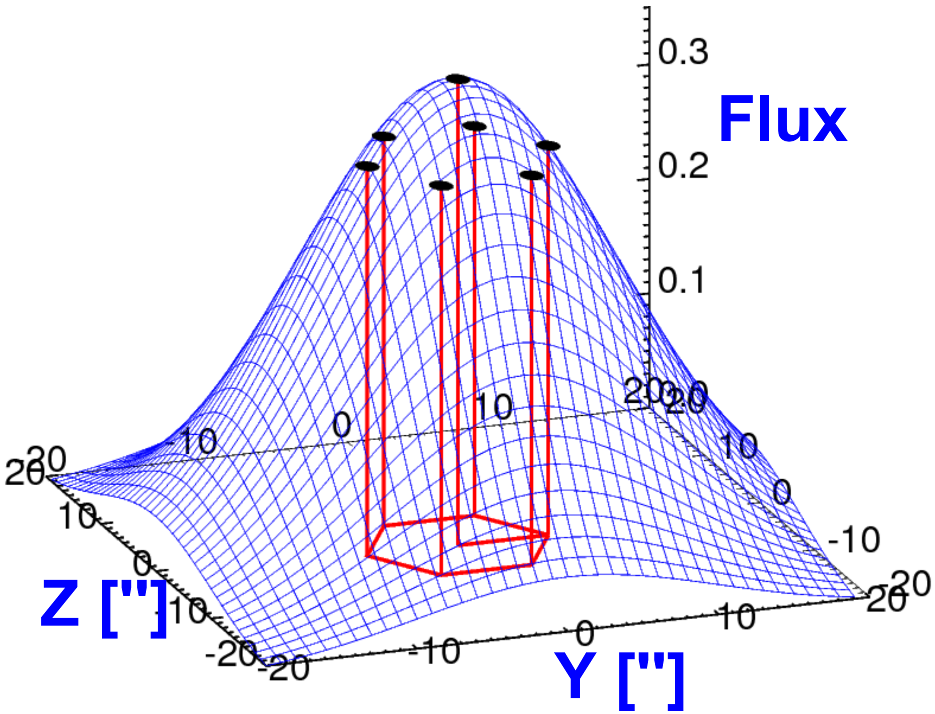
- Denodding:
  - For Point Source: $S = [S_{A1} + S_{A2} – S_{B1} – S_{B2}]/4$
  - For Small Map: $S = [S_A – S_B]/2$
- Output is **Level 1 product** for Point Source & Small Map
  - Contains one **demodulated flux per jiggle position per detector**
- *Note for the demo: denodding task has a bug in 0.6.7*

Point source photometry

- The flux measured by the **Primary** detector in the 7 jiggle position.
- This final step performs a 2D fitting of the 7 fluxes with a known profile.
- The total flux and position of the source is determined.
- **Level 2 product** contains the **flux** of the source in each band, the measured **position** and fit quality

•**No imaging** is planned for this observing mode

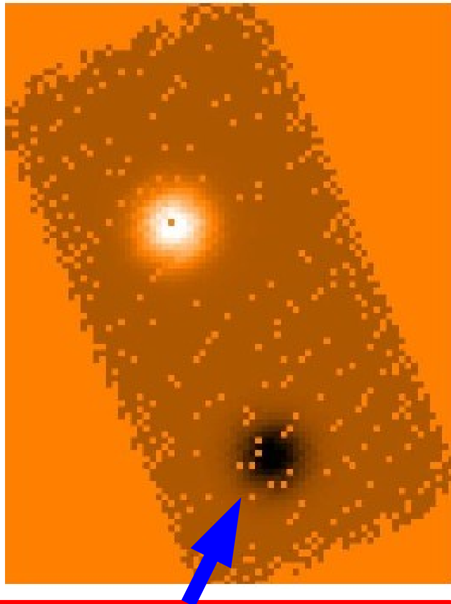




Regrid (Naïve Map making)

- Final step of Small Map pipeline is to regrid data onto sky
- Re-griding (or Naïve map making) consists in:
  - For each sample, assign the flux to the nearest pixel
  - For each pixel, average on the assigned fluxes
- MADmap type methods cannot be used since the signal is not measured at a single time

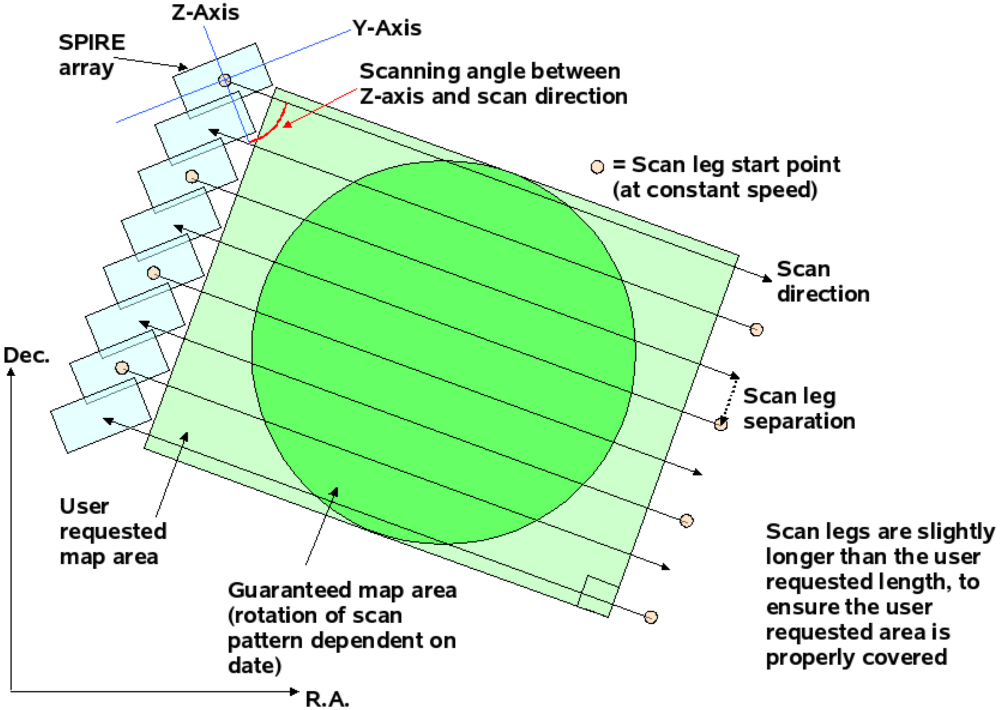
- For Small Map observations, the **Level 2 products are 3 images, one for each band**.
- Source extraction and photometry are not part of the pipeline and are left to the astronomer
  - Source extraction, aperture photometry tools are available in HIPE



Negative beam will not appear with final pipeline

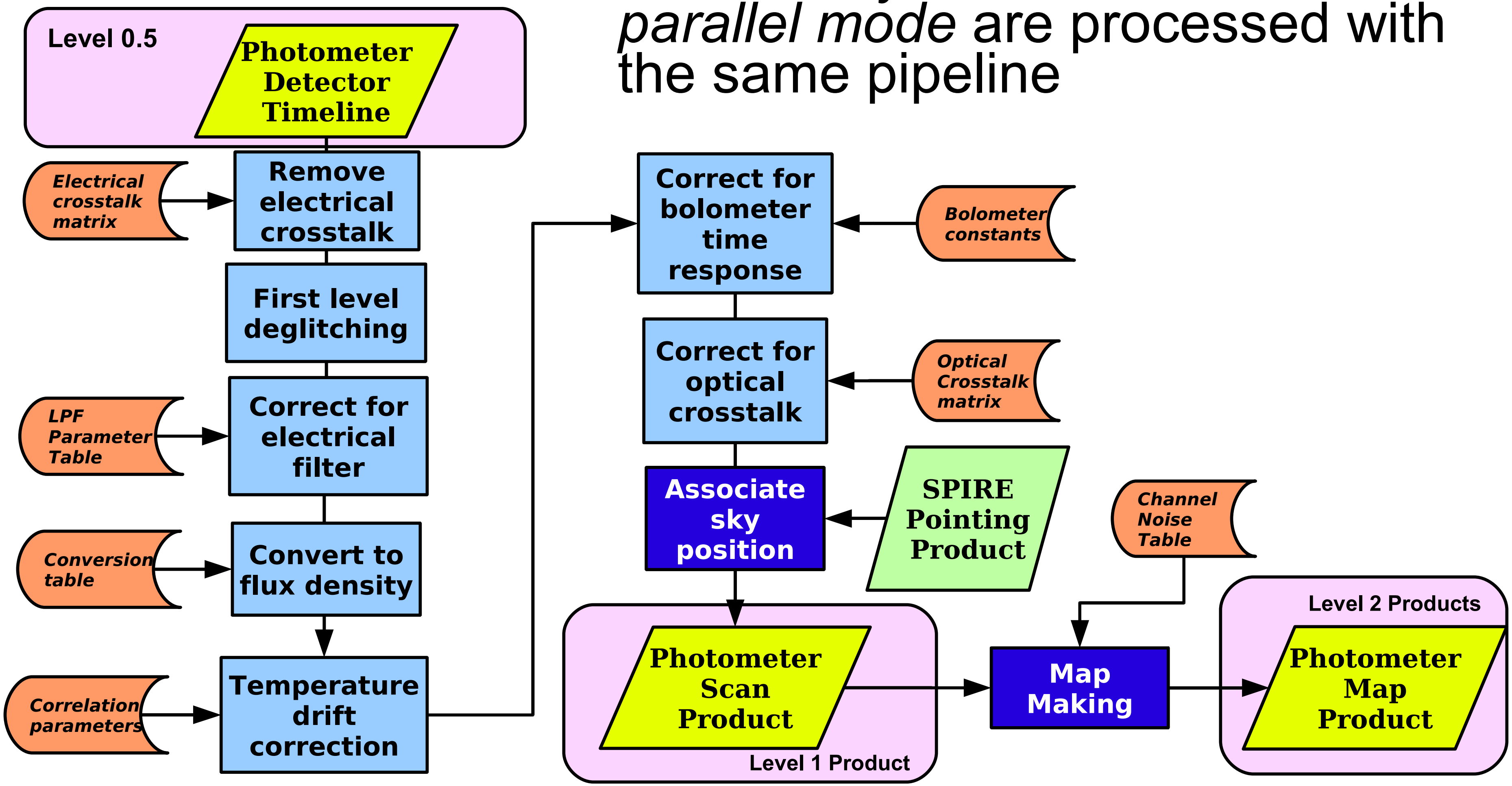
Large Map (& Parallel) Observing Mode

- Optimized for observations of large fields
- Performed by moving the telescope at constant speed
- The scan direction shall be at a “magic” angle (42.4°) from the array axis
- If only SPIRE is used, it is possible to cross-linking in a single observation
- Sampling rate 18.6Hz (10Hz in parallel mode)



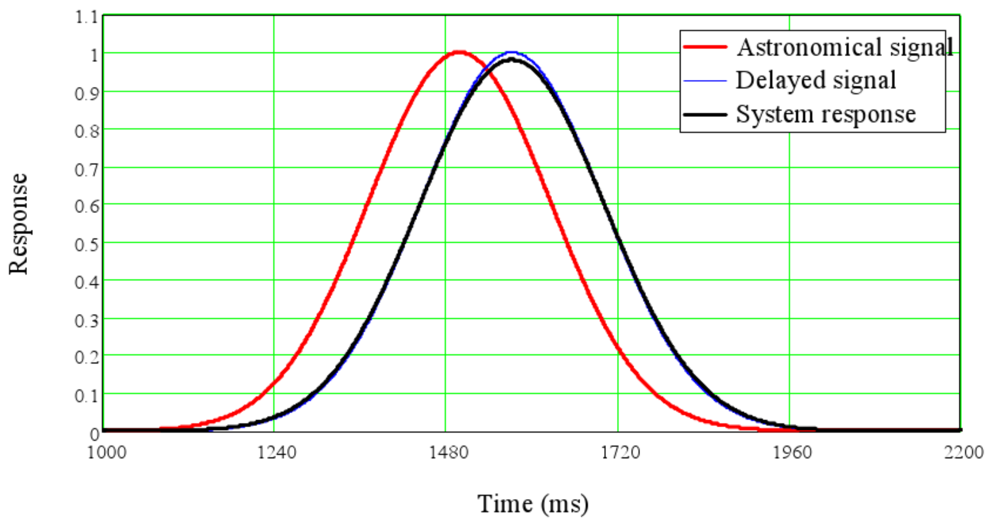
Large Map (& Parallel) Pipeline

- *SPIRE only* and *SPIRE+PACS parallel mode* are processed with the same pipeline

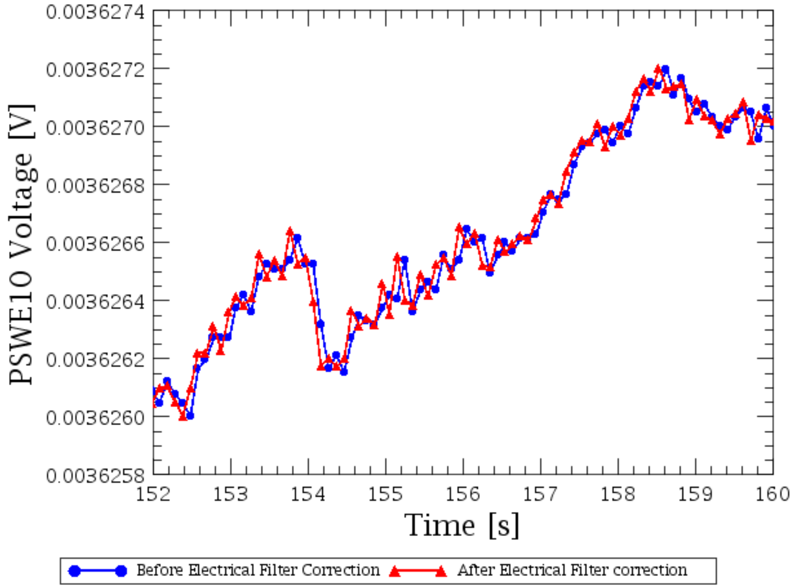


Electrical filter correction

- The low pass filter in readout electronics changes the response of the system. In the case of scanning on a source in the beam, the effect is a delayed signal slightly attenuated (~2%)



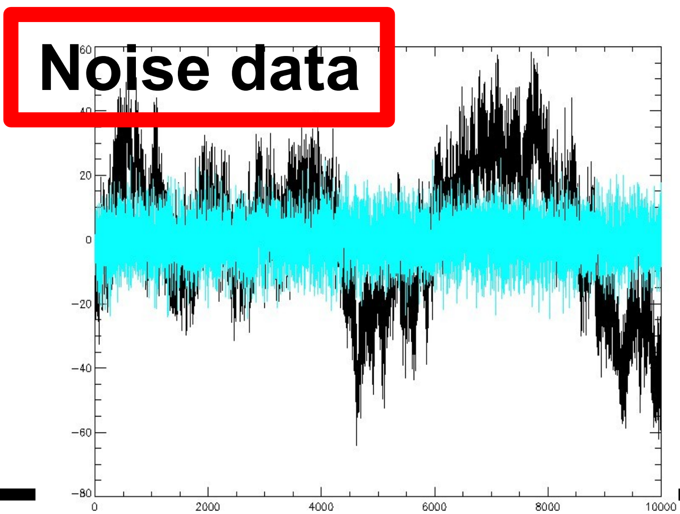
- Baseline approach: transform in frequency domain, divide by the electrical filter function and re-transform back
- Backup option: make a simple time shift

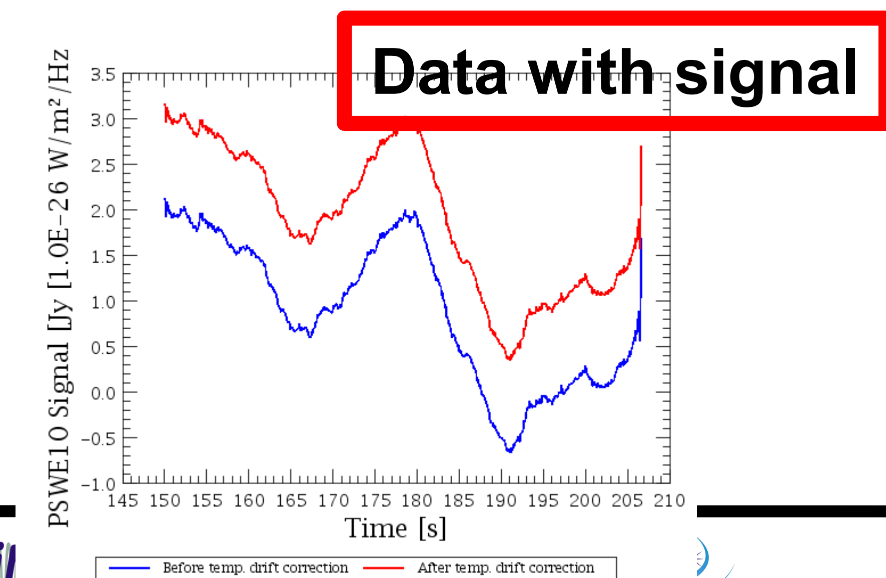


Temperature drift correction

- Most of **low frequency noise** in SPIRE detectors is due to the **drift** of the detector **arrays bath temperature**
- Temperature drift can be corrected using the signal of thermistors (Vth) or dark detectors that are on each array
- This module corrects for the difference between flux conversion constants derived at a reference bath temperature and their value at the actual temperature

$$S_{corr}(t) = S(t) - \left\{ A \cdot \left[\bar{V}_{th}(t) - V_{th0} \right] + B \cdot \left[\bar{V}_{th}(t) - V_{th0} \right]^2 \right\}$$





Map making (MADmap)

- Default map making algorithm for Large Map is MADmap (Cantalupo, 2002)
- MADmap is a Maximum likelihood method:

$$S(t) = \boldsymbol{A} \cdot f(\vec{x}) + n(t)$$

Measured signal — Pointing matrix — Signal in sky — Noise

Noise covariance matrix

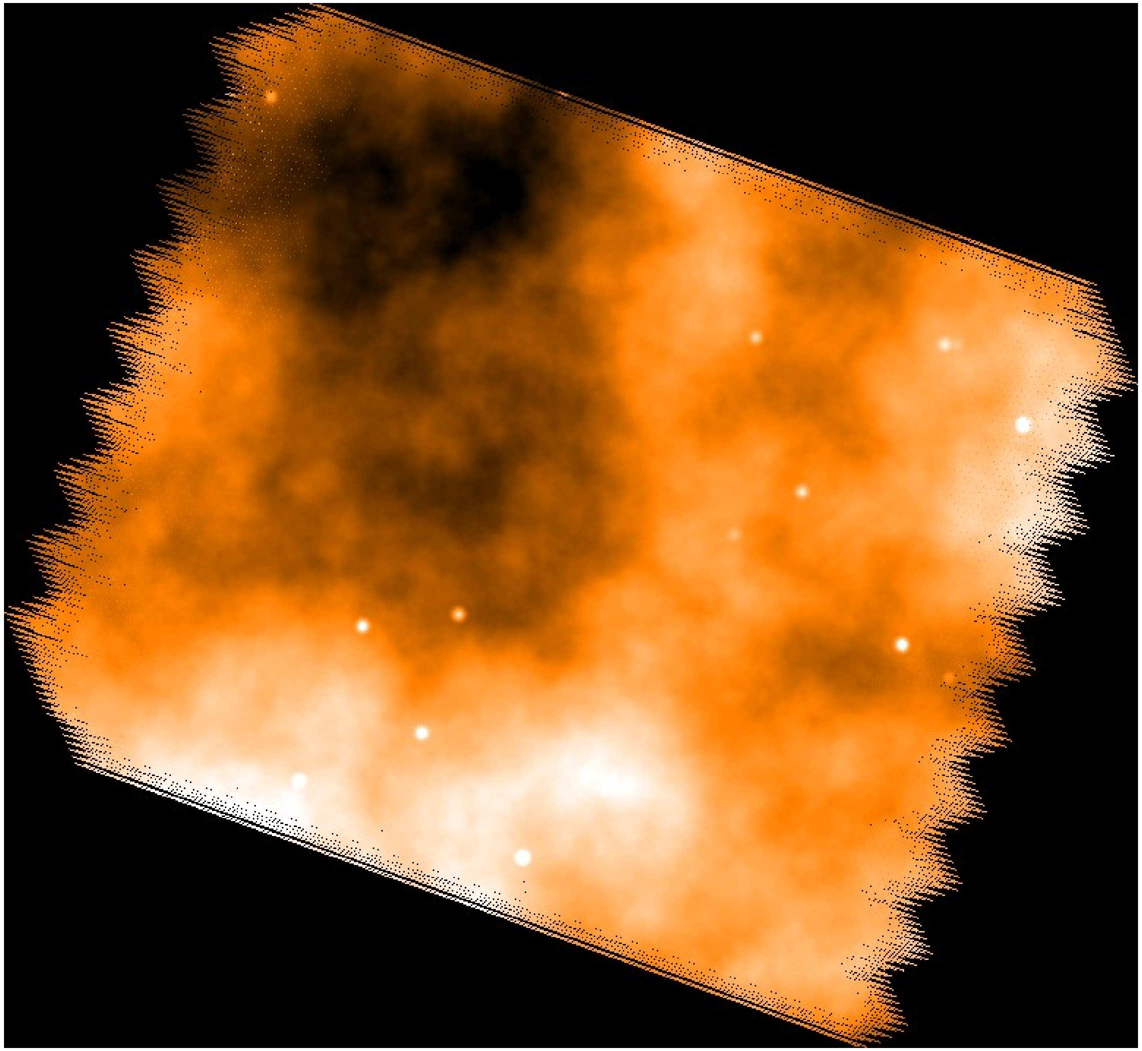
$$\boldsymbol{N} = \langle \vec{n}\,\vec{n}^{T} \rangle$$

Reconstructed map

$$f(\vec{x}) = \left(\boldsymbol{A}^{T} \boldsymbol{N}^{-1} \boldsymbol{A}\right)^{-1} \boldsymbol{A}^{T} \boldsymbol{N}^{-1} \vec{S}$$

- Limitations: noise shall be Gaussian, additive and not spatially (detector vs detector) correlated
- Temperature drift correction makes this algorithm good for SPIRE

SPIRE Map making level 2 product



Cross-linking in Parallel mode

- Cross-linking is not possible in a single Parallel mode observation
  – Typically 2 observations with perpendicular scanning directions have to be requested
- ESA processing is observation-based i.e. **each observation is processed independently**
- You will need to combine the 2 observations and **execute the map making** by yourself!
- However, it will be shown in the demo!!