SPIRE photometer pipelines and data products

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Pipeline development & validation

- The development of pipelines is distributed between several institutes based on their expertises. Algorithms and development plans are specified by the ICC.
- The SPIRE Configuration Control Board is in charge of supervising the development SPIRE software.
- Automatic testing of pipeline tasks is performed every night. In addition, the pipelines are tested by an ESAC operator every few weeks.
- Beginning in the Summer 2008, the SPIRE ICC began a **Scientific Validation** activity to review the algorithms, documentation and implementation of pipelines.

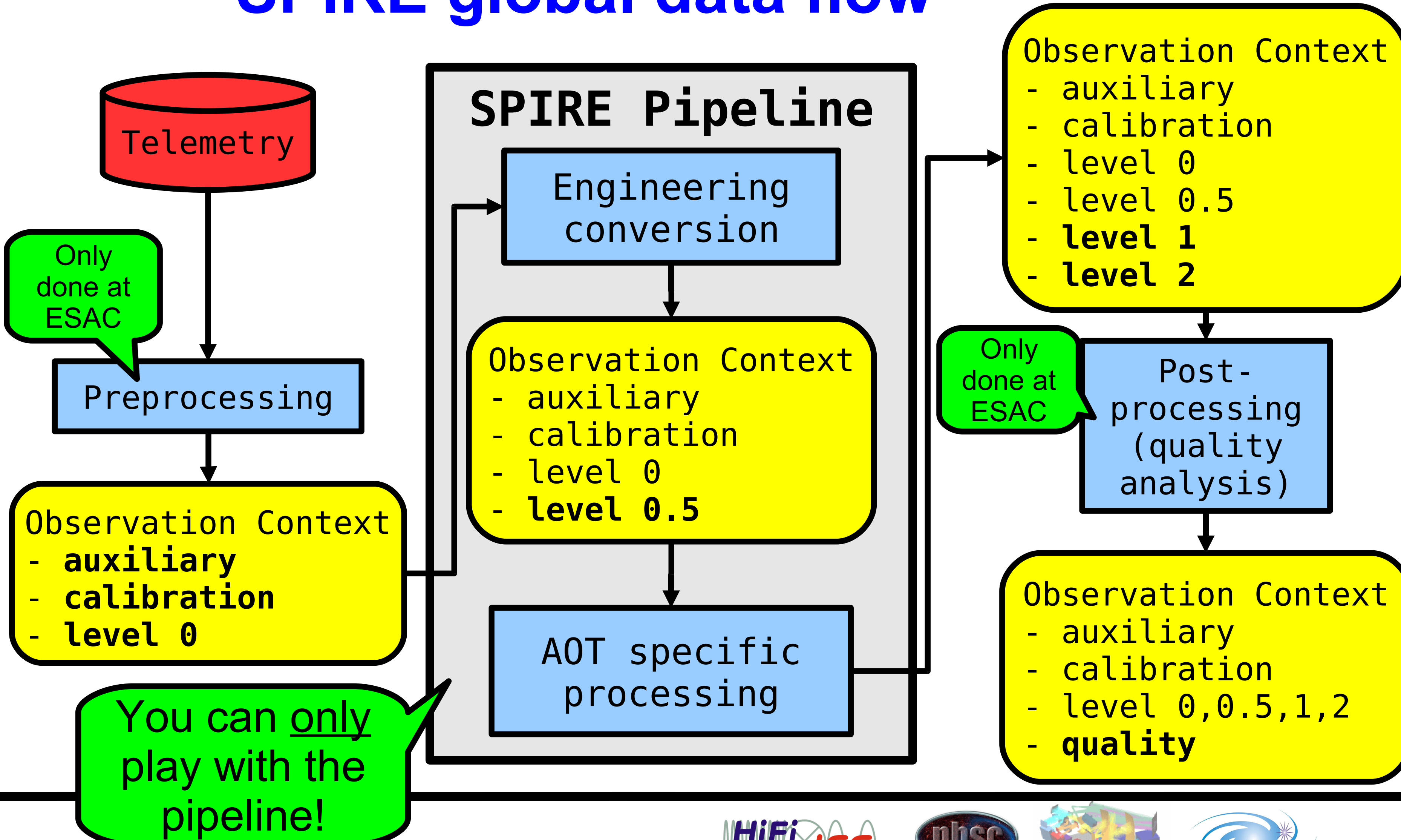
SPIRE Pipeline implementation

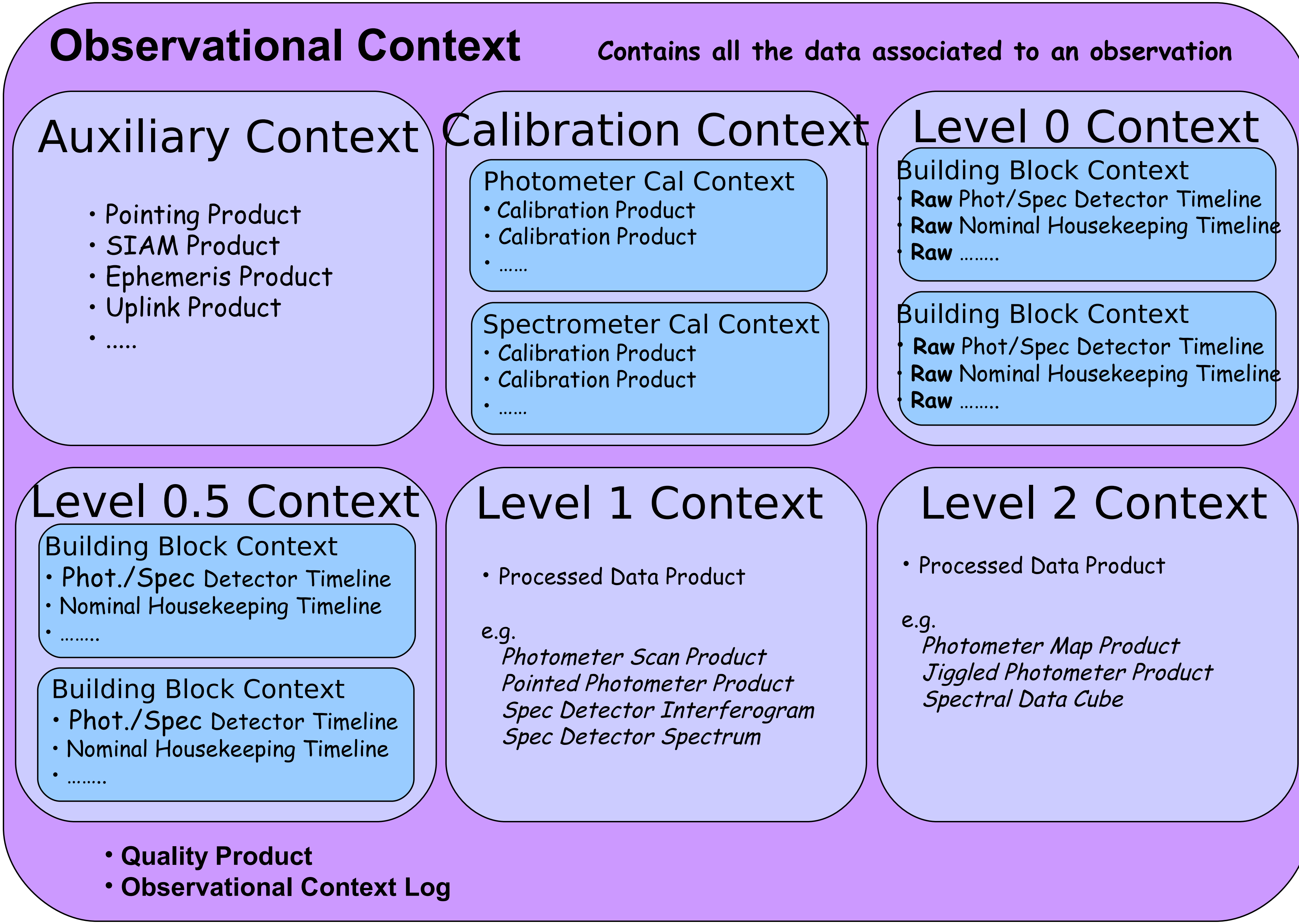
- The pipelines are implemented as a sequence of **Tasks** each performing a specific process/correction on to data.
- All Tasks are written in **Java** (mainly for performance)
- Each pipeline is implemented as a **Jython script** that passes data (in form of **Products**) between Tasks. No computation is carried out in pipeline scripts
- There is one pipeline script for each instrument mode
- Pipelines and tasks will be flexible enough to allow users to carry out Interactive Analysis using different strategies.

Photometer pipelines status

- Almost all tasks written and implemented in the pipelines!
- Issues requiring attention:
  - Ensure that tasks and pipelines are user-friendly for IA
  - Moving coordinate frames for targets with large motion
  - Calibration files to be update after launch (PV phase)
- Functionalities and documentation being reviewed and tested as part of an ongoing Science Validation process
  - We will have good confidence in the pipelines flow and algorithms at launch!

SPIRE global data flow

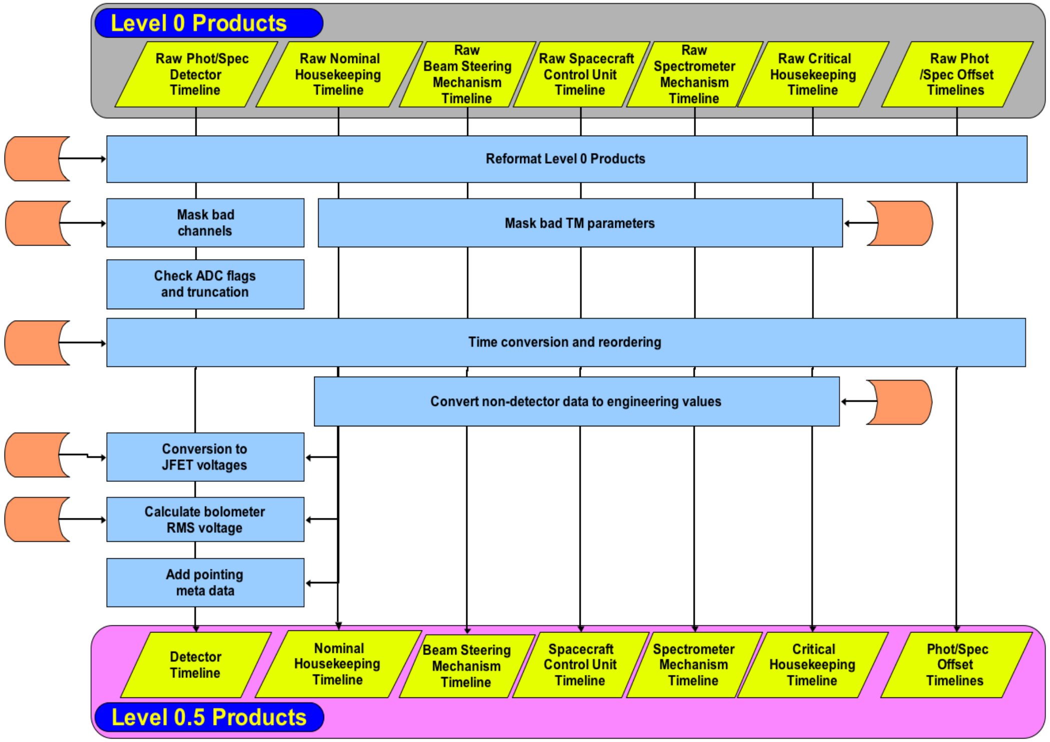



Observational Context
Contains all the data associated to an observation
Auxiliary Context
• Pointing Product
• SIAM Product
• Ephemeris Product
• Uplink Product
• .....
Calibration Context
Photometer Cal Context
• Calibration Product
• Calibration Product
• ......
Spectrometer Cal Context
• Calibration Product
• Calibration Product
• ......
Level 0 Context
Building Block Context
• Raw Phot/Spec Detector Timeline
• Raw Nominal Housekeeping Timeline
• Raw ....
Building Block Context
• Raw Phot/Spec Detector Timeline
• Raw Nominal Housekeeping Timeline
• Raw ....
Level 0.5 Context
Building Block Context
• Phot./Spec Detector Timeline
• Nominal Housekeeping Timeline
• ....
Building Block Context
• Phot./Spec Detector Timeline
• Nominal Housekeeping Timeline
• ....
Level 1 Context
• Processed Data Product
e.g.
Photometer Scan Product
Pointed Photometer Product
Spec Detector Interferogram
Spec Detector Spectrum
Level 2 Context
• Processed Data Product
e.g.
Photometer Map Product
Jiggled Photometer Product
Spectral Data Cube
• Quality Product
• Observational Context Log

Engineering Conversion stage

- **Engineering conversion** processing stage is common to all SPIRE pipelines.
- Converts **raw telemetry** values (Level 0 products) into **engineering values**, e.g. ADUs into voltages, resistances, temperatures...(Level 0.5)
- Level 0.5 data will be the **best starting point** for your interactive analysis.

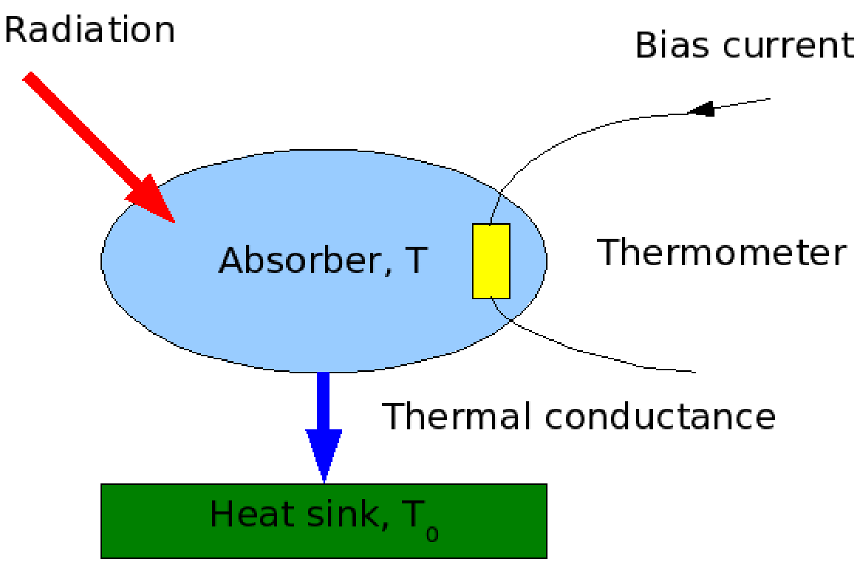
Level 0 products

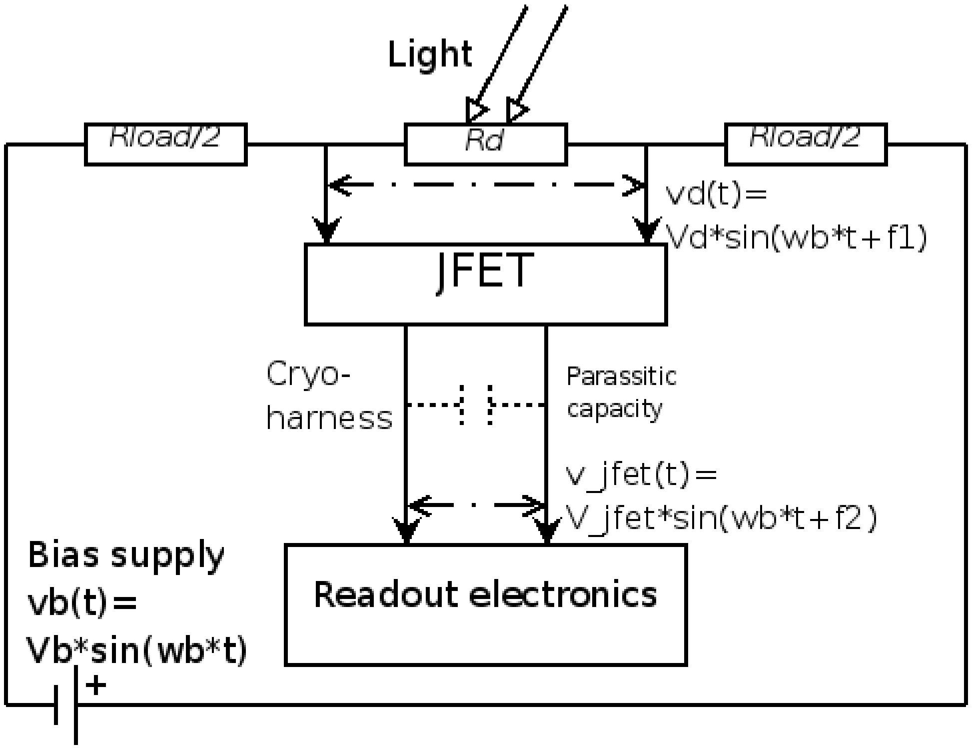


Level 0.5 products

SPIRE detectors

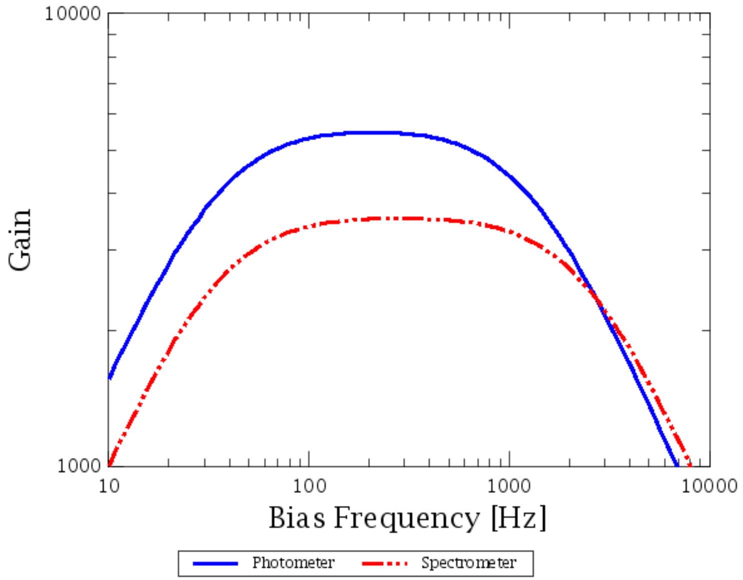
- SPIRE detectors are basically resistors whose **resistance** is dependent on the **temperature**. The temperature correspondingly depends on the **flux**.





Convert raw ADUs to JFET voltages

- $V_{JFET\text{-}RMS} = 5 \cdot (DATA - 16384 + 52428.8 \cdot OFF) / (G(\omega_b) \cdot 65535)$
  - DATA = raw detector readout (from 0 to 65535)
  - OFF = ADC offset (from 0 to 15)
  - $G(\omega_b)$ = readout electronics gain



- $G(\omega_b)$ constants are stored in the channel gains calibration product
- Nominal photometer bias frequency: 131Hz

From JFET to detector voltages

- The voltage at the JFET output ($V_{JFET-RMS}$) shall be corrected to compute the real detector voltage
- $V_{d-RMS}=V_{JFET-RMS}/[H_{JFET}|H_H(\omega_b)|\cos(\Delta\varphi)]$
  - H_{JFET} is the JFET gain (=0.96)
  - $H_H(\omega_b)$ is the cryo-harness transfer function
  - $\Delta\varphi$ is the phase shift introduced by the harness
- $R_d=R_L \cdot V_{d-RMS}/(V_{b-RMS}-V_{d-RMS})$
- Calculated in an iterative procedure

Level 0.5 Detector Timelines structure

- A Photometer/Spectrometer Detector Timeline (PDT or SDT) contains 3 main tables: **`voltage`**, **`resistance`** and **`mask`**.
- These tables contain a first column with the **sample time** (in TAI), and a column for each channel
- The **`mask`** table contains the **flags** for each sample

sampleTime [TAI]	PSWR1 []	PSWD16 []	PSWT1 []	PSWB16 []	PSWC15 []	PSWA15 []	PSWD15 []	PSWB15 []	PSWC14 []
1.6071967670...	0	0	129	0	0	0	280	0	0
1.6071967670...	0	0	129	0	0	0	280	0	0
1.607196									
1.607196									
1.607196									
1.607196									
1.607196									
1.607196									
1.607196									
1.607196									
1.607196									

sampleTime [TAI]	PSWR1 [Ω]	PSWD16 [Ω]	PSWT1 [Ω]	PSWB16 [Ω]	PSWC15 [Ω]	PSWA15 [Ω]	PSWD15 [Ω]	PSWB15 [Ω]	PSWC14 [Ω]
1.607196767...	5250873.5	3179357.5	1.402949...	2876428.8	3685223.5	2789554.2	-180418....	2976251.5	3143544.8
1.607196767...	5250914.0	3179469.8	1.402945...	2876351.0	3685155.2	2789585.0	-180418...	2976188.2	3143576.5
1.607196767									
1.607196768									
1.607196768									
1.607196768									
1.607196768									
1.607196768									
1.607196768									
1.607196768									
1.607196768									

sampleTime [TAI]	PSWR1 [V]	PSWD16 [V]	PSWT1 [V]	PSWB16 [V]	PSWC15 [V]	PSWA15 [V]	PSWD15 [V]	PSWB15 [V]	PSWC14 [V]
1.6071967670...	0.005254...	0.003523...	0.010026...	0.003232...	0.003966...	0.003155...	-2.40433...	0.003320...	0.003500...
1.6071967670...	0.005254...	0.003523...	0.010025...	0.003232...	0.003966...	0.003155...	-2.40433...	0.003320...	0.003500...
1.6071967677...	0.005254...	0.003523...	0.010025...	0.003232...	0.003966...	0.003155...	-2.40433...	0.003320...	0.003500...
1.6071967680...	0.005253...	0.003523...	0.010025...	0.003232...	0.003966...	0.003155...	-2.40433...	0.003320...	0.003500...
1.6071967680...	0.005254...	0.003523...	0.010025...	0.003232...	0.003966...	0.003155...	-2.40433...	0.003320...	0.003500...
1.6071967683...	0.005254...	0.003523...	0.010025...	0.003232...	0.003966...	0.003154...	-2.40433...	0.003320...	0.003500...
1.6071967684...	0.005254...	0.003523...	0.010026...	0.003232...	0.003966...	0.003155...	-2.40433...	0.003320...	0.003500...
1.6071967684...	0.005254...	0.003523...	0.010026...	0.003232...	0.003966...	0.003155...	-2.40433...	0.003320...	0.003500...
1.6071967685...	0.005254...	0.003523...	0.010025...	0.003232...	0.003966...	0.003155...	-2.40433...	0.003320...	0.003500...
1.6071967686...	0.005254...	0.003523...	0.010025...	0.003232...	0.003966...	0.003155...	-2.40433...	0.003320...	0.003500...
1.6071967687...	0.005254...	0.003523...	0.010025...	0.003232...	0.003966...	0.003155...	-2.40433...	0.0033207	0.003500...
1.6071967687...	0.005254...	0.003523...	0.010025...	0.003232...	0.003966...	0.003155...	-2.40433...	0.003320...	0.003500...

SPIRE Building Blocks

- SPIRE observations are composed of building blocks (BB). The instrument performs a single basic operation in each BB (e.g. execute a scan line in a map).
- The data you will receive in Level 0 context and Level 0.5 context are divided into these building blocks.

Observation Context

Level-0.5 Context

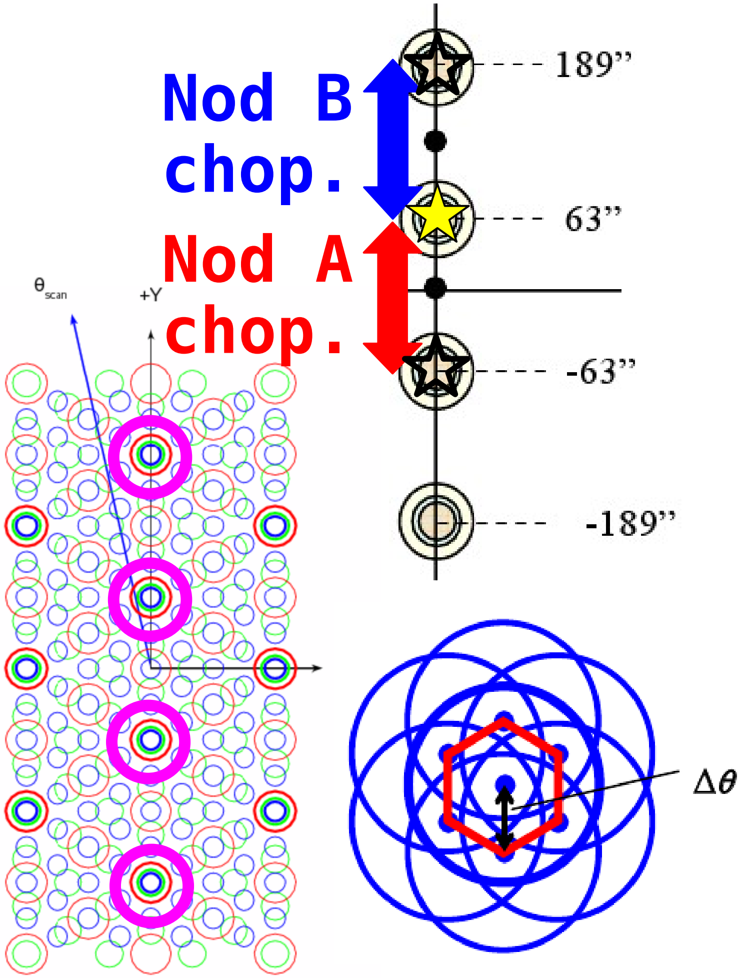
Building Block Context

*converted **timelines**, grouped per Building Block*

Photometer Detector Timeline: PDT (18.6 Hz)
Housekeeping Timeline: NHKT (1 Hz)
BSM timeline: BSMT (64 Hz)

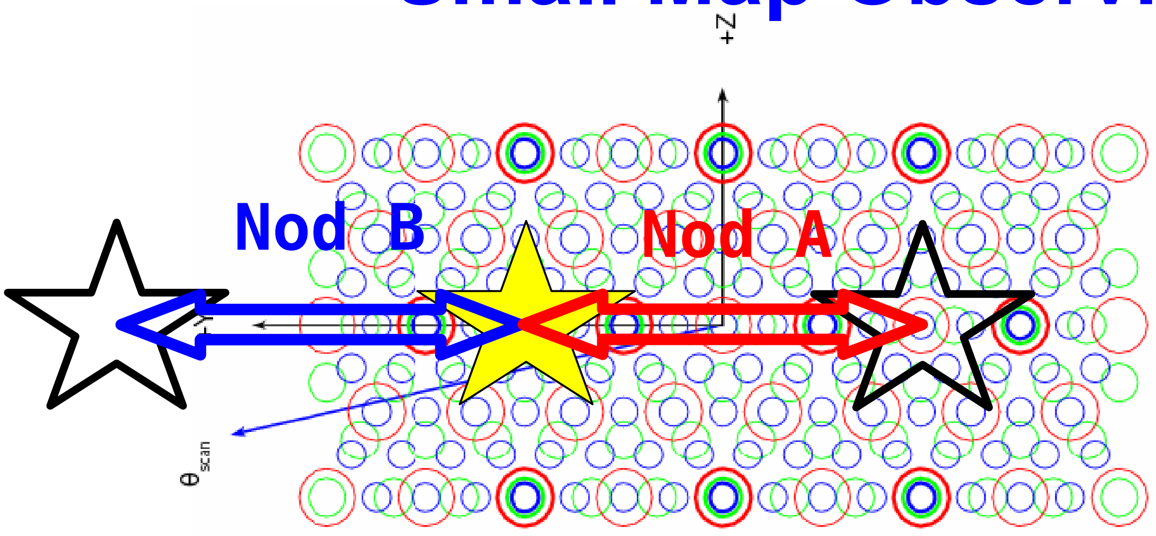
Building Block Context

Point Source Observing Mode

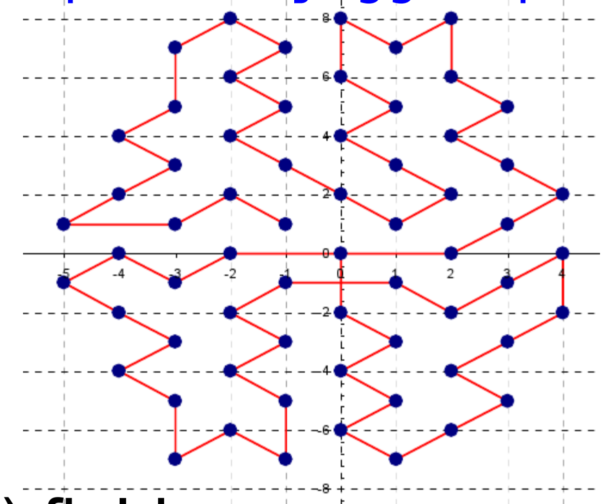


- Optimized for compact sources
- The instrument chops by ±63" with the BSM to remove background (sky and telescope).
- The telescope performs one or more **ABBA** nodding sequences to remove asymmetries in optics and in telescope background
- A 7-point mini-map (ΔΘ=6", i.e. 1/3 of PSW detector beam)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

Small Map Observing Mode



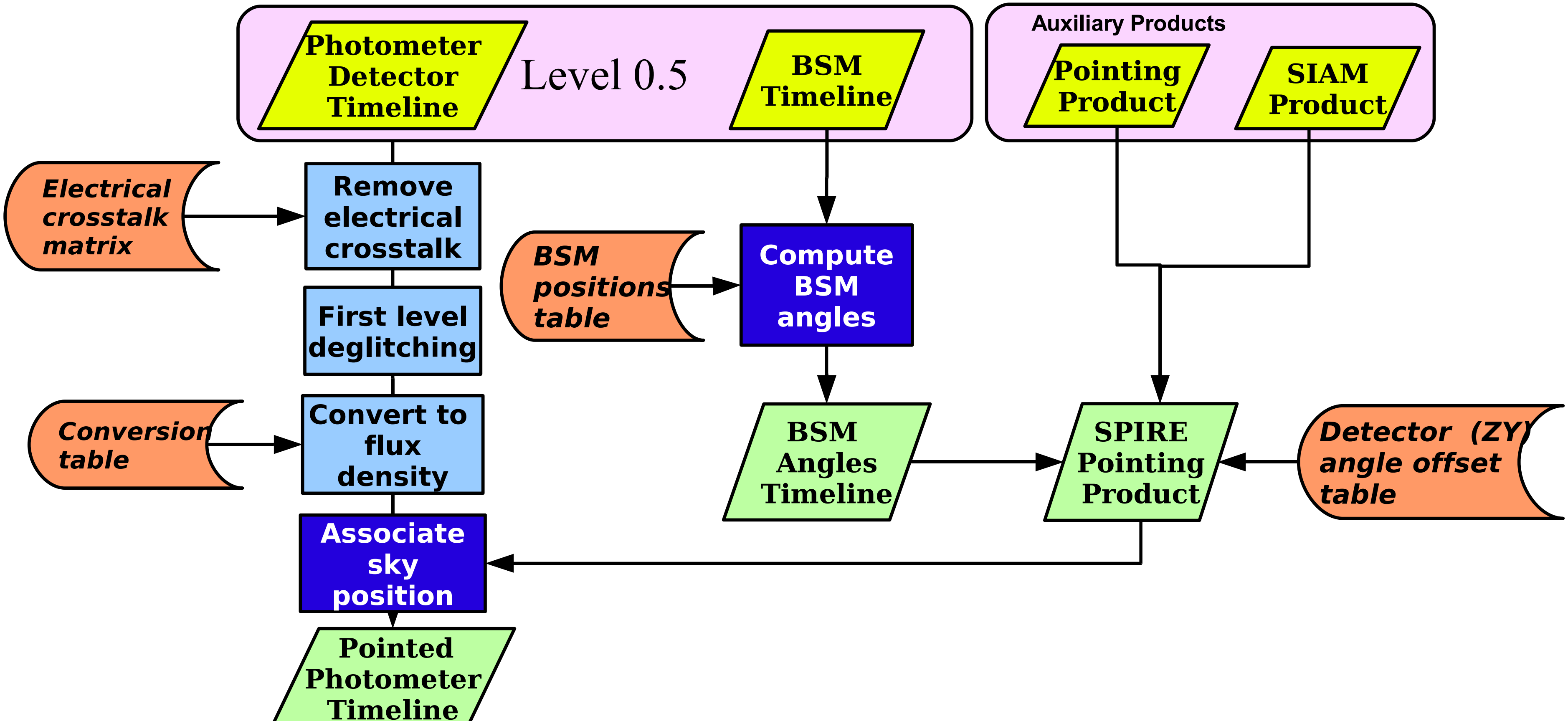
64 points jiggle path



- 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 ±120'' (therefore in nod position B, the observed field is chopped outside the array.)

Point Source & Small Map pipeline

- First pipeline stage flowchart



Remove Electrical crosstalk

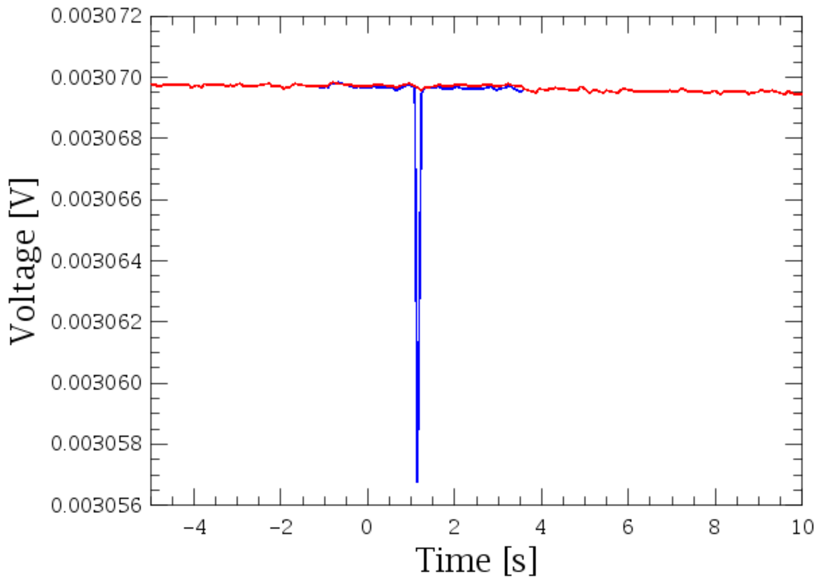
- Electrical crosstalk arise from:
  - Capacitative/inductive coupling between readout channels
  - Change in applied bias voltage due to loading of bias supply
- Assuming that crosstalk is linear and constant we have:

$$\begin{bmatrix} V_1^c \\ V_2^c \\ V_3^c \\ \ldots \end{bmatrix} = \begin{bmatrix} 1\, e_{21}\, e_{31} \ldots \\ e_{12}\, 1\, e_{23} \ldots \\ e_{13}\, e_{23}\, 1 \ldots \\ \ldots\ldots\ldots \end{bmatrix} . \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ \ldots \end{bmatrix}$$

- Analysis of data taken during instrument tests suggest that crosstalk is very small

First level deglitching

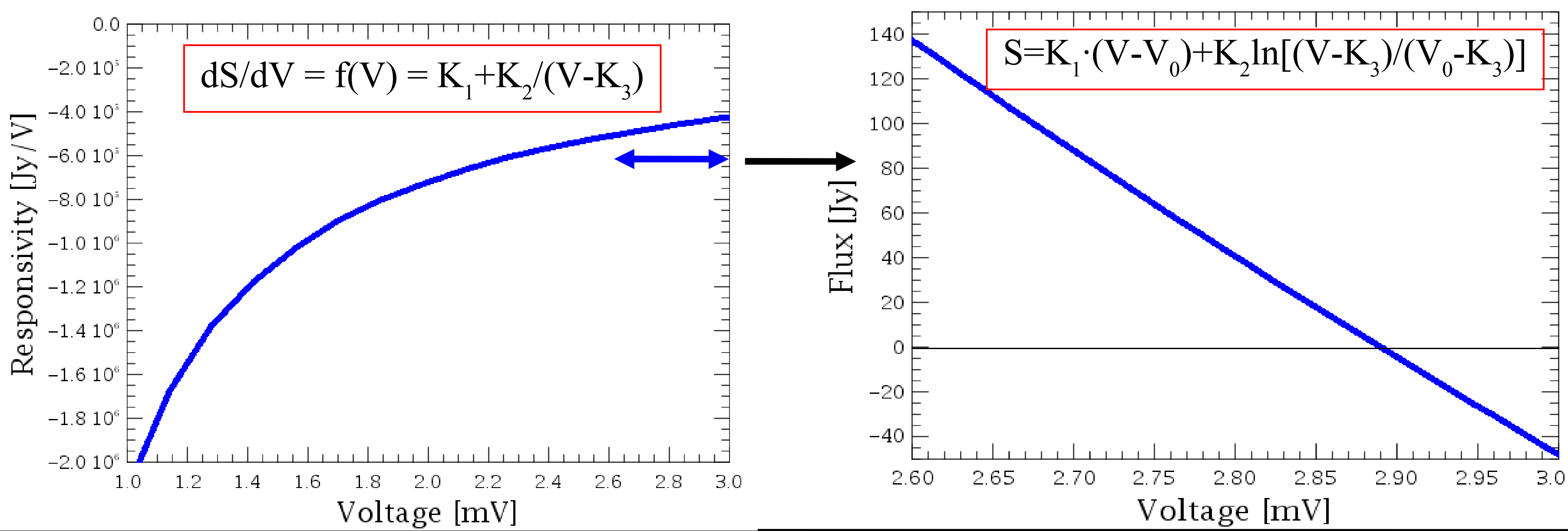
- Effects are rather simple
  - No change in responsivity
- Deglitching algorithm is based on regularity & wavelets analysis (see poster)
- Same algorithm used in spectrometer and photometer pipelines
- Glitches are identified and removed
- Signal reconstruction not yet optimized



- Using wavelets, this method is also possible on modulated data

Photometer Flux Conversion

- Responsivity dS/dV was 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

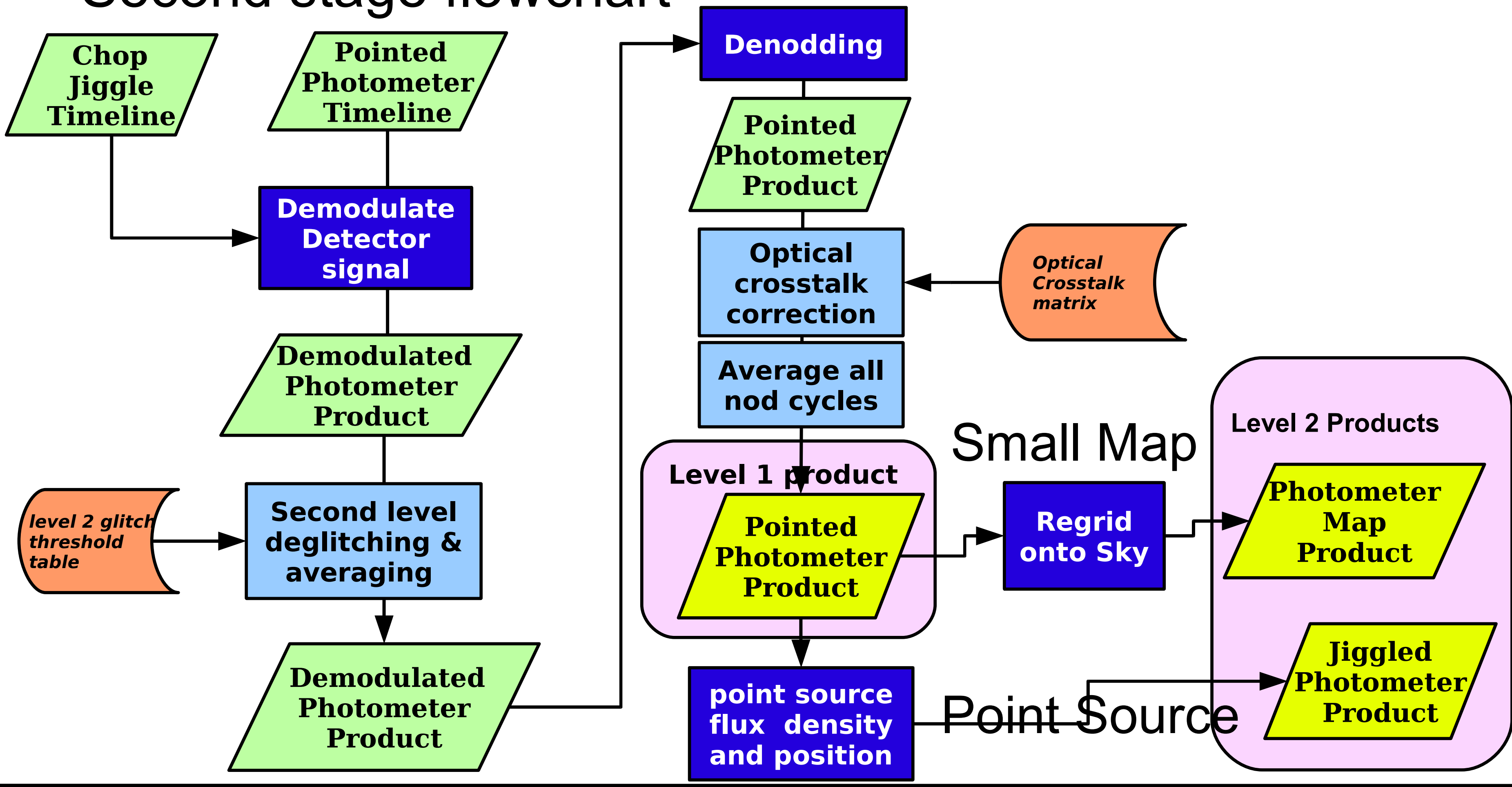


Associate Sky Positions

- To know the position in sky where each detector is looking, we require:
  - 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

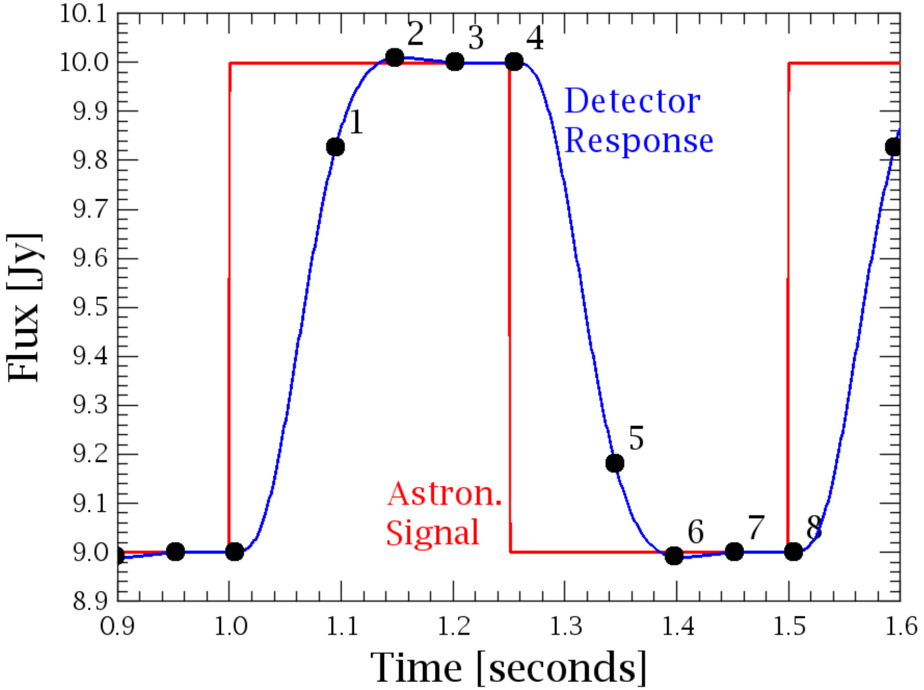
Point Source & Small Map pipeline

- Second stage flowchart



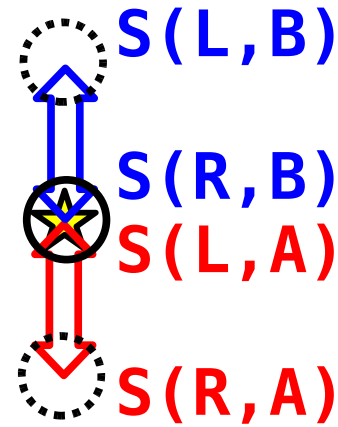
Demodulation

- 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 we 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 $k=0...N_{chop}$

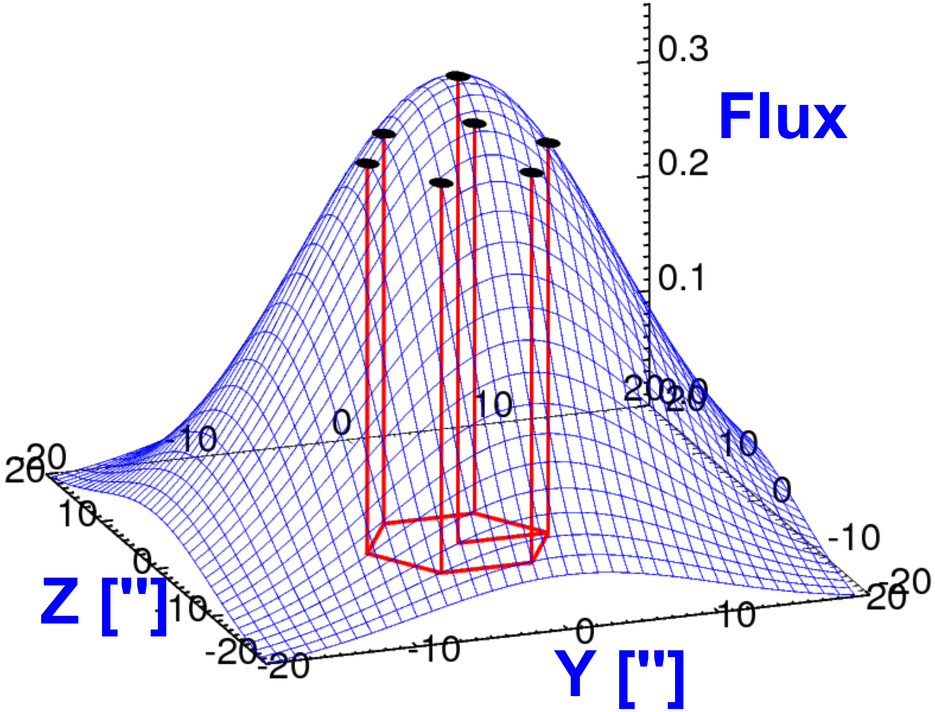
Jiggle averaging & Denodding



- 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 a Level 1 product for Point Source and Small Map observations
  - Contains one flux per jiggle position per detector

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



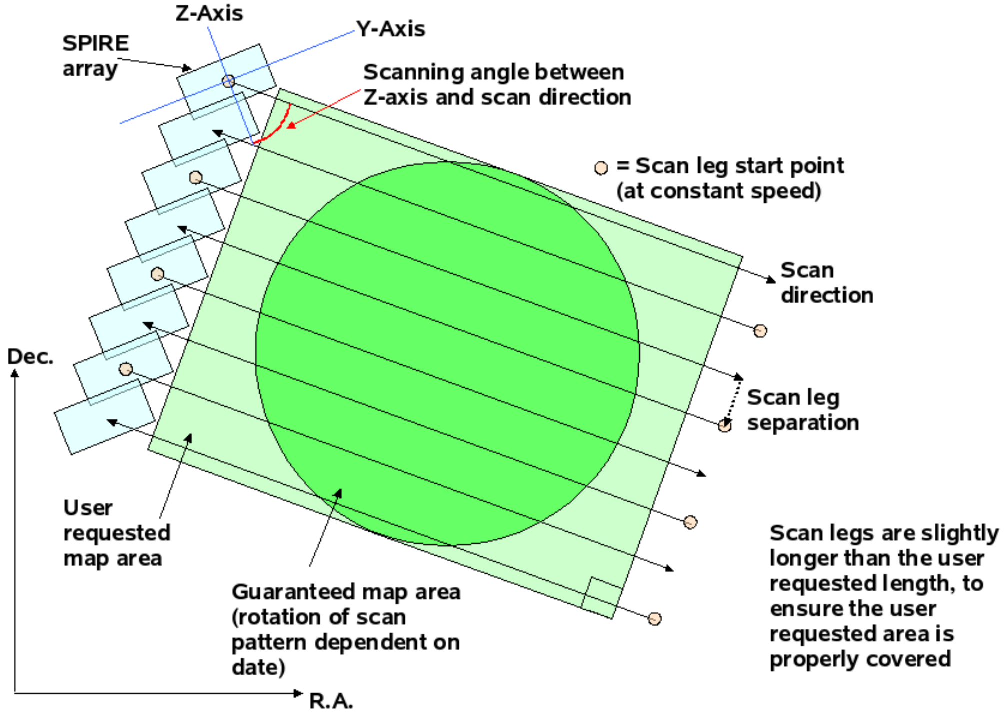
Regrid (Naïve Map making)

- 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
  - See presentations from Anthony Smith on source extraction, and Sara Regibo on aperture photometry

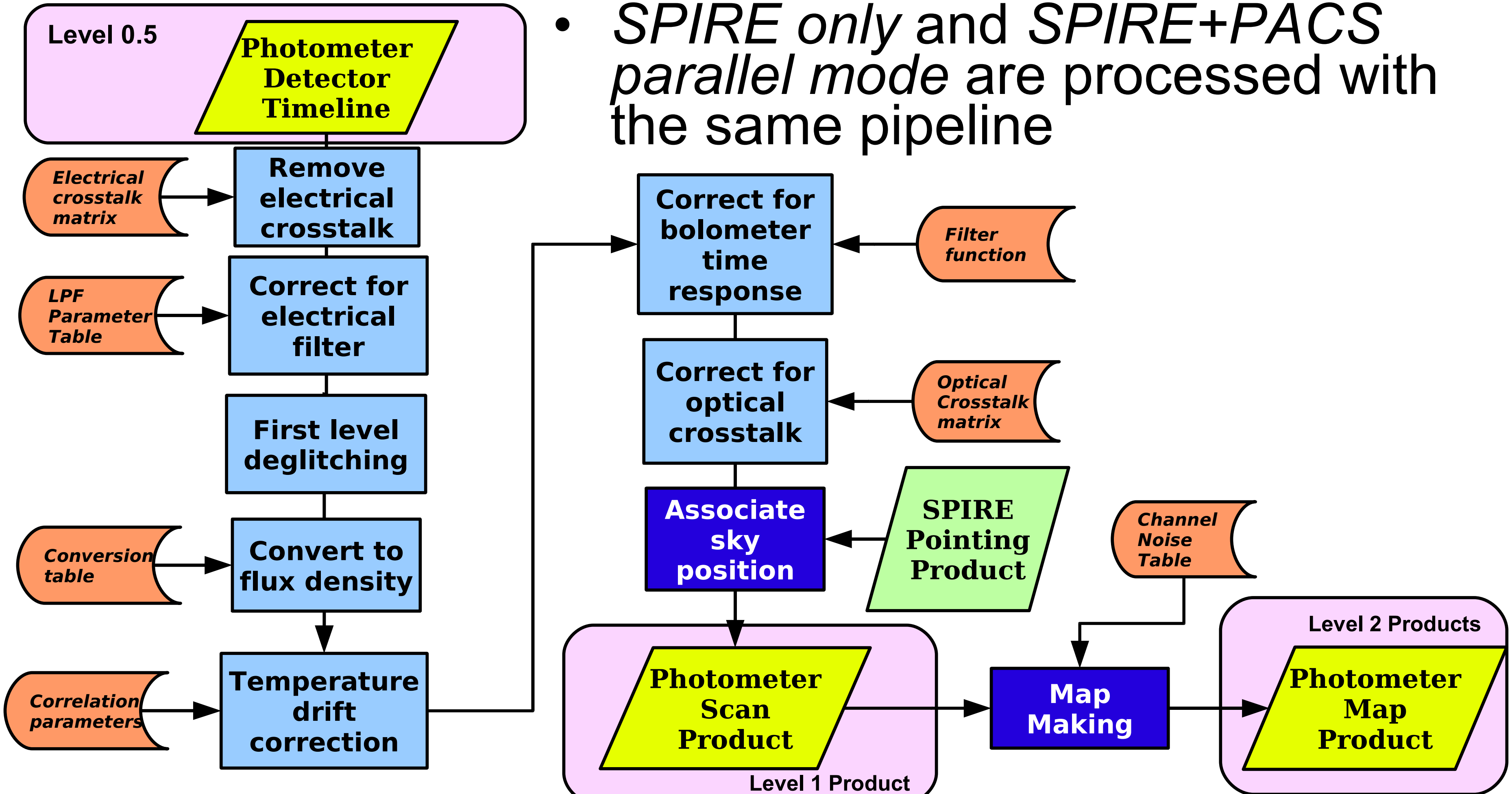
Large Map (& Parallel) Observing Mode

- 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

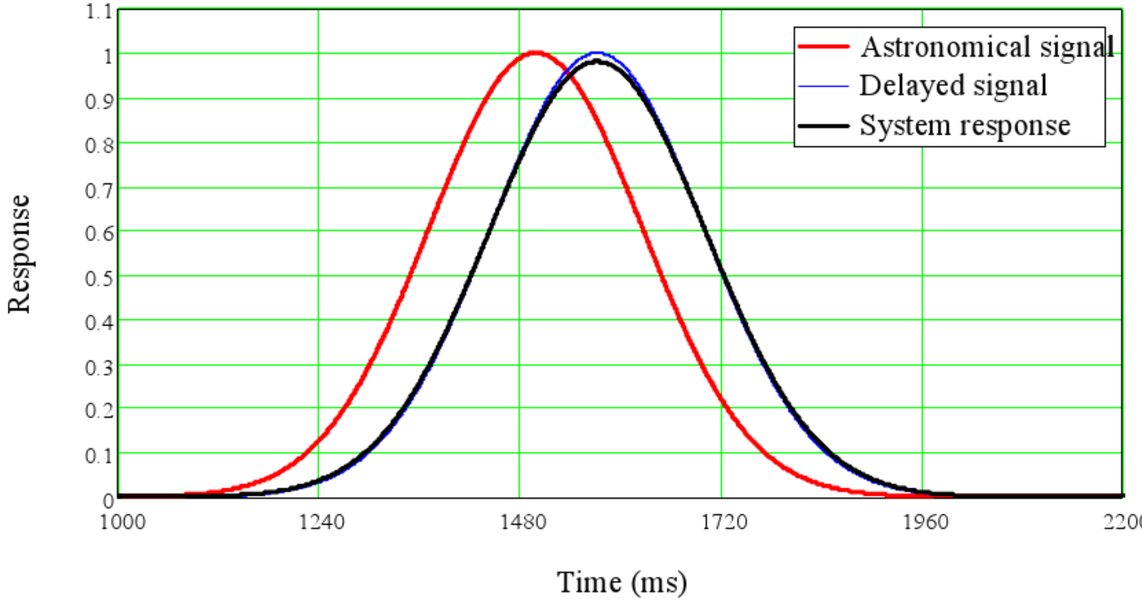
- *SPIRE only* and *SPIRE+PACS parallel mode* are processed with the same pipeline



Electrical filter correction

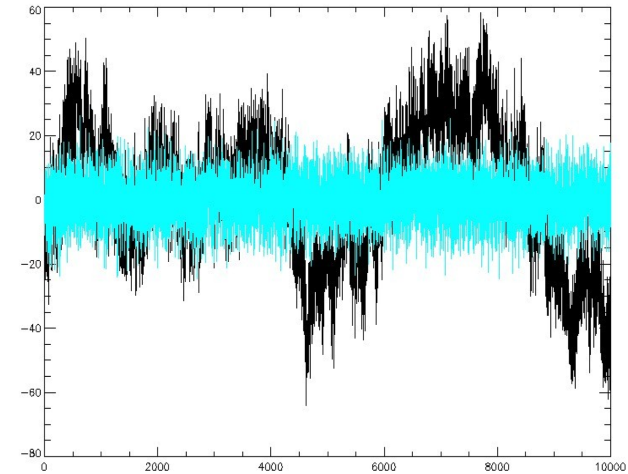
- The low pass filter in readout electronics changes the response of the system. In the case of scanning on a source in the beam, the effect is a delayed signal slightly attenuated (~2%)

- Two options:
  - Transform in frequency domain, divide by the electrical filter function and re-transform back
  - Make a simple time shift (backup option)



Temperature drift correction

- **Most of low frequency noise** in SPIRE detectors is due to the **drift** of the detector arrays **temperature**
- Temperature drift can be corrected using the signal of **thermistors** (V_{th}) or dark detectors that are on each array
- Thermistor signal shall be smoothed



$$S_{corr}(t) = S(t) - \left\{ A \cdot \left[\bar{V}_{th}(t) - V_0 \right] + B \cdot \left[\bar{V}_{th}(t) - V_0 \right]^2 \right\}$$

Bolometer response correction

- Thermal capacity of bolometers changes system response
- Correction uses same approach as Electrical Filter Correction

Map making (MADmap)

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

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

Measured signal — Pointing matrix — Signal in sky — Noise

Noise covariance matrix

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

Reconstructed map

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

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

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!!

Data volumes & requirements

- Data volumes assuming Large Map observations:
  - Telemetry: 43 MB/hour
  - Level 0 products: **90 MB/hour**
  - Level 0.5 products: **430 MB/hour**
  - Level 1 products: **560 MB/hour**
  - Level 2 products: 90 MB/hour (just a guess!)
- Time needed to process data on 2GHz computer: **~1/5** of observation length (not linear!)
- Memory requirements are difficult to quantify
  - Smart usage of *PAL* heavily decreases memory needs
  - 2GB seems enough for 7 hours long observations

The End

- The SPIRE developers team hopes you will enjoy playing with SPIRE pipelines!

- Any feedback is very welcome!

- Any question??