« Map Making for the Extended Emission » Working group

Alain Abergel

IAS, Orsay

Extended emission with SPIRE:

- Most of the GT observations
- Photometer: Mainly large scan maps, but also small maps
- Main problems:
    - "1/f noise"
    - Hot telescope
    - Under-sampling of the PSF
    - Absolute calibration (punctual sources---> extended emission)
    - Non-linearities, which may depend on the angular scales

- Same problems for the FTS + spectral dimension
    - Two modes of observations are under-sampled : "Sparse" and "Intermediate"
    - One fully sample mode

SPIRE Consortium, Oct. 31, 2007

« Map Making for the Extended Emission » Working group

Last meeting, October 11, IAS, Orsay

- Around 20 participants (but late announcement)

Agenda :
- ICC developments for SPIRE (photometer): Pierre Chanial
- ICC developments for PACS (photometer and spectroscopy): Marc Sauvage
- Bayesian inversion of SPIRE data: François Orieux
- Observing modes for the extended emission : Edward Palehampton

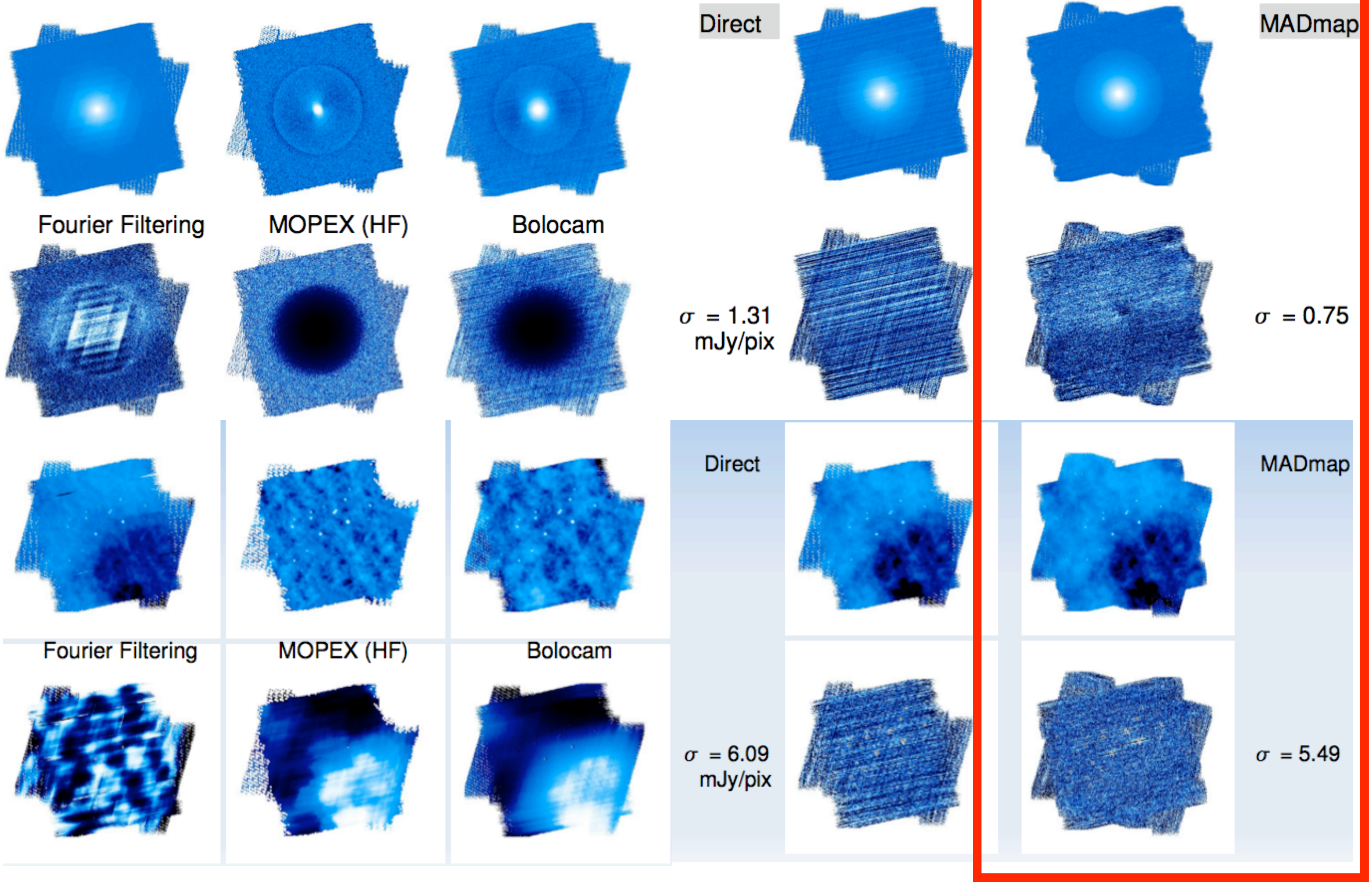
Presentations: http://www.ias.u-psud.fr/spire/index_workshop_11oct2007.html

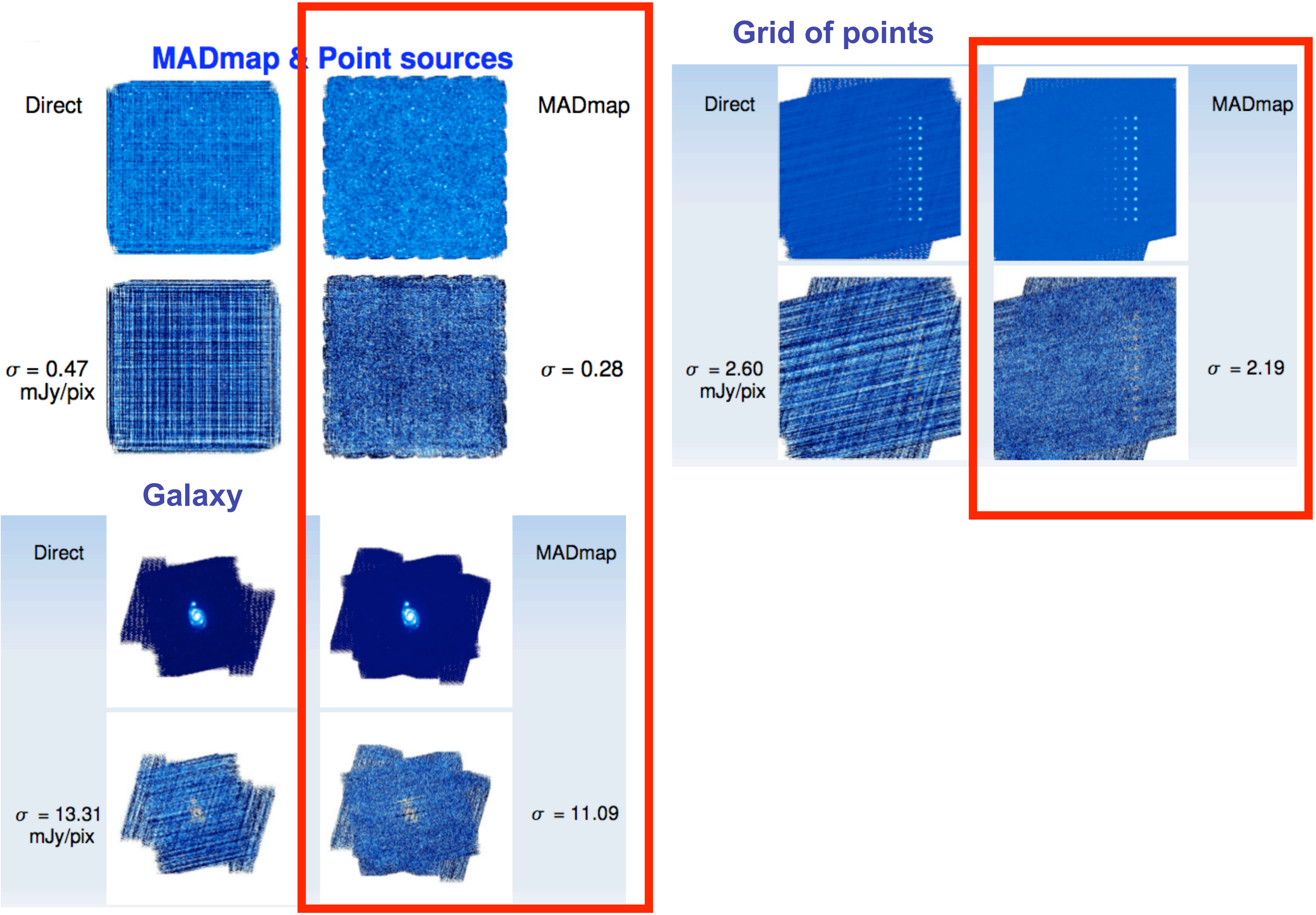
SPIRE/ICC map making (photometer, scan maps)

Pierre Chanial

- Two pipelines:
  - Standard (co-adding)
  - Maximum likelihood estimator: MADmap
    (selected by a review panel in September 2006)

Difficulties: 1/f & extended sources




MADmap & Point sources
Direct
MADmap
σ = 0.47
mJy/pix
σ = 0.28
Grid of points
Direct
MADmap
σ = 2.60
mJy/pix
σ = 2.19
Galaxy
Direct
MADmap
σ = 13.31
mJy/pix
σ = 11.09

Maximum likelihood estimator: MADmap

Formalism:

$$\underset{\text{TOD}}{d_t} = \underset{\text{pointing matrix}}{A_{tp}}\, \underset{\text{map}}{\Delta_p} + \underset{\text{noise}}{n_t}$$

Classic:

$$\hat{\Delta} = \underbrace{(A^T A)}_{\text{density map}}{}^{-1} \underbrace{A^T d}_{\text{sum of fluxes}}$$

ML:

$$\hat{\Delta} = \underbrace{(A^T N^{-1} A)^{-1}}_{\text{pixel domain noise covariance matrix}} \underbrace{A^T N^{-1} d}_{\text{weighted sum of fluxes}}$$

- **Take advantage of spatial redundancy and of a noise characterization (the time-time noise covariance matrix $N=\langle nn^T \rangle$) to remove 1/f noise**
- **For gaussian noise, the resulting map is the max. likelihood map.**
- **Madmap main job is to invert $A^T N^{-1} A$ (n^2 matrix where $n \sim 10^6$ is the number of observed pixels in the output map)**

MADmap : Status and limitations

- **Done:** implementation (instrument independent) and SPIRE interface (also PACS)
- **Residuals:** σ decreased by a factor around 2 compared to the standard algorithm
- It has been shown from MADmap results that **cross-linking is essential** (Wasket et al. 2007)
- To do: compute error maps
- Should give good results for the extended emission

Limitations :

- MAPDmap solves linear equations:

  data = P sky + noise, where P is a pointing Matrix
- Additive noise,
- Gaussian noise and only uncorrelated 1/f noise across the array,

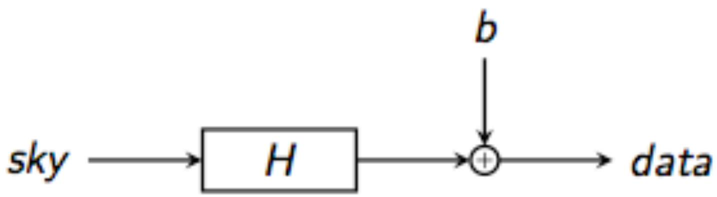
  the correlated 1/f noise and non-gaussian events (glitches) must be removed before using MADmap,
- No deconvolution: reconstruction of the map convolved by the beam and the feedhorn apertures,
- No super-resolution (gain of angular resolution in case of over-sampling of the PSF)
- No correction for non-linearities.

Bayesian inversion of SPIRE data for the extended emission

François Orieux, Laboratoire des Signaux et Systèmes (LSS, SUPELEC) + IAS

Jean-François Giovannelli (LSS), Thomas Rodet (LSS), Alain Abergel (IAS)

Approach : inversion of the instrument



- Acquisition $data = H(sky) + b$
- H instrument model
- b errors of measurement / modeling

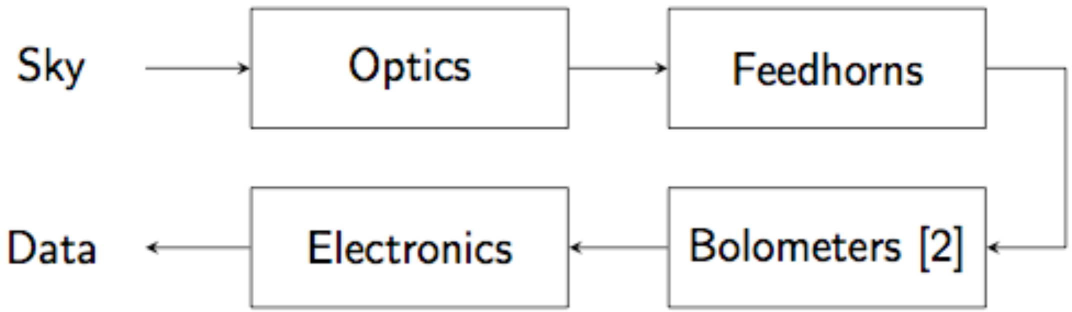
MADmap: data = P sky + noise,
P is a pointing matrix

$\Longrightarrow$ **Estimate** sky given $data$: $\widehat{sky} = \Psi(data)$

Instrument model

Objectives

- Explain the data (information, physical effects,. . .)
- Realistic
- Fast



- Optics (well known)
  - Linear response : Airy disc
  - Emissive telescope (**still open**)
- Feedhorns (well known)
  - Spatial sensor integration
  - Gaussian window
- Bolometer (working on)
  - Linear or non-linear model
  - Thermal drift of the system
  - Influence of cosmic ray
- Electronics (still open)
  - influence on the bolometer system

Bayesian estimation

Using probabilities [1]

Posterior law :

$$p(sky|data) = \frac{p(data|sky)p(sky)}{p(data)} \begin{cases} \text{sky} & \text{unknwon} \\ \text{data} & \text{given} \quad \text{(data)} \end{cases}$$

1. Instrument model $\Rightarrow data = H(sky) + b$
2. Noise law $\Rightarrow$ likelihood $p(data|sky)$
3. Prior law $\Rightarrow p(sky)$

Choice of a point estimate

- Maximum
- Mean

[1] G. Demoment, « Image Reconstruction and restoration : Overview of common estimation structure and problems. », *IEEE Trans. ASSP*, 1989.

Computation of the estimator

- Maximum *a posteriori*

$$\hat{sky}_{MAP} = \arg\max_{sky} p(sky|data) = \arg\min_{sky} J(sky)$$

  - Simple model :
    $J(sky) = ||data - H(sky)||^2$ give a stable solution
  - More realistic model :
    $J(sky) = ||data - H(sky)||^2 + \lambda||D(sky)||^2$ needed
  - Computation : gradient descent, ...

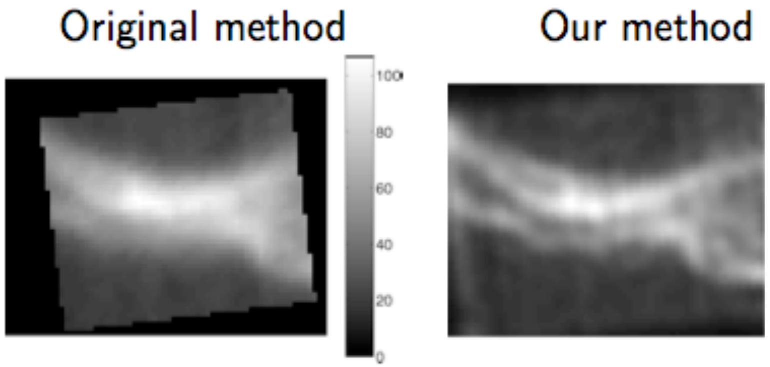
- Mean *a posteriori*

$$\hat{sky}_{EAP} = E_{sky|data}[sky] = \int_{sky} sky \; p(sky|data) dsky$$

  - Symmetrical law : $\hat{sky}_{MAP} = \hat{sky}_{EAP}$
  - Computation : Laplace, MCMC, ...

Example and work to be done for SPIRE

- Inversion of IRS/Spitzer data (Rodet et al., in prep.)



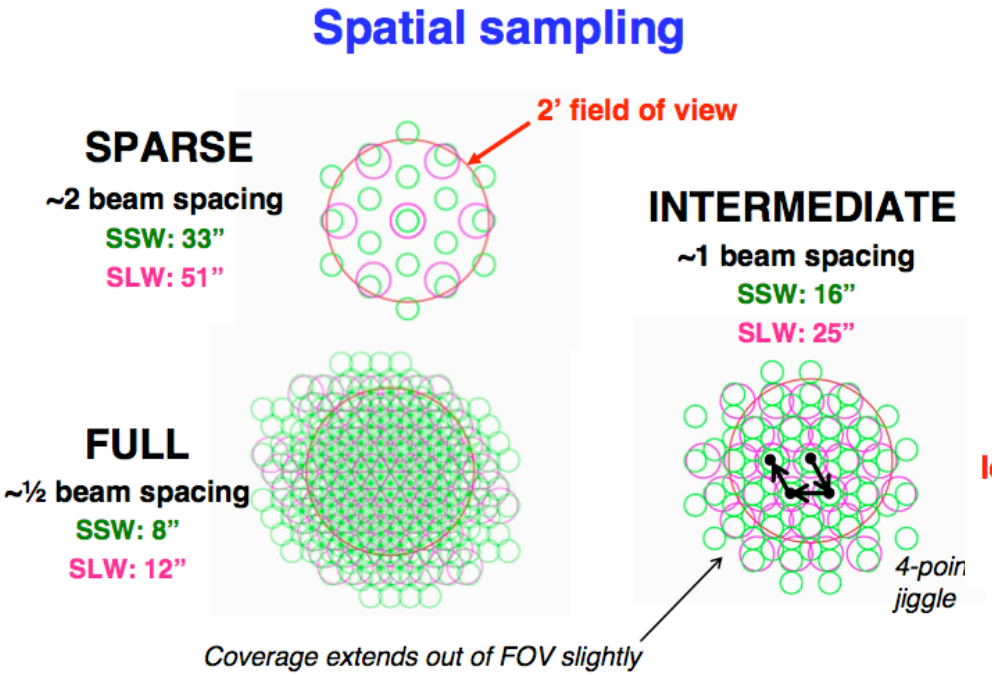
- Model instrument
- Prior information
 (e.g., high frequency content of the sky)
- Global approach

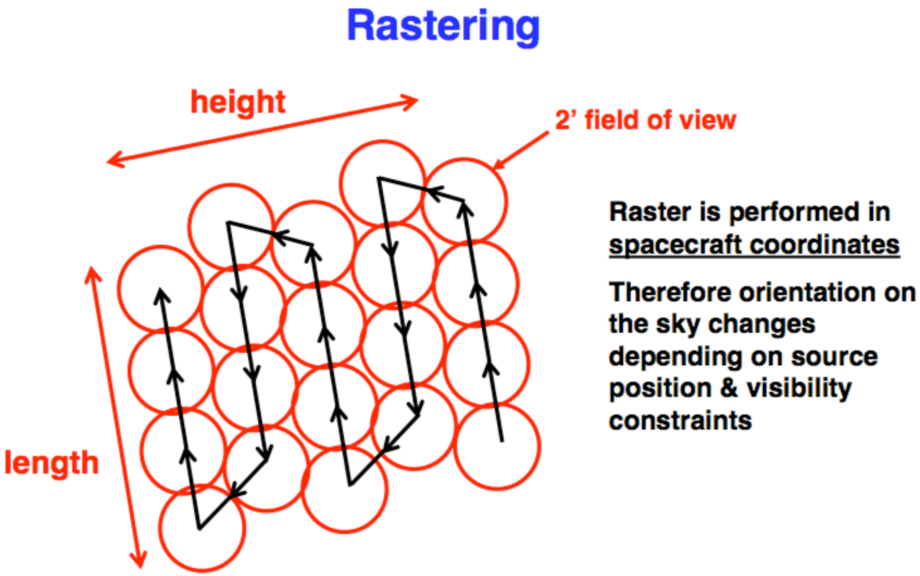
Deblurring (deconvolution)
Super-resolution (in case of over-sampling)

- To be done for the photometer of SPIRE:
    - Instrument model (almost done)
    - Bayesian estimator (on going)
    - Inversion of simulated data
    - Validation
    - Pipeline

Mapping with the SPIRE Spectrometer

Edward Polehampton





Data products: - Level 1: List of spectra for all single pixels
- Level 2: gridded spectral cubes ?

The Full sampled data should contain all information to compute gridded spectral cubes (except a hole due to 1 dead pixel, SSW-D5)

Conclusions

SPIRE Photometer

- One powerful tool developed within the ICC (MADMAP)
  - Version 1.0 in March 2008
- Promising tool based on the inversion of an instrument model
  - First tests for simulated SPIRE data: mid-2008
  - New pipeline for scan maps: early/mid 2009
  - Could also be adapted for small maps, and (maybe) the FTS

Other important aspect: Photometric calibration for the extended emission