SUPREME: a SUPer REsolution Mapmaker for Extended emission

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General Context

- Joint project between astrophysical (IAS) et signal processing (L2S) teams
- Use knowledge of both communities to introduce better methods
- SPIRE: Thesis F. Orieux 2009.
- SUPREME v1 (Matlab) : Orieux et al 2012 [OGR+12],
- SUPREME v2 (Matlab, HIPE plugin BETA): Ayasso et al 2012 [ARA12b].
  - High resolution maps: up to 3 times compared to classical Coadd mapmakers.
  - 2 instrument pointing models and 2 Instrument beam model.
  - A Gaussian noise model with variable offsets to achieve map destripping.
  - Automatic method (all hyperparameters are estimated)
  - Seamless mask integration.
  - Error and interval of confidence maps.
  - Controlled equivalent beam model.

General Context

Data Model

$$\mathbf{y} = \mathbf{H}\mathbf{x}$$

- $\mathbf{y}$: a collection of sky observations (data).
- $\mathbf{x}$: unknown sky.
- $\mathbf{H}$: system transfer function (instrument/forward Model).

Objective

1. Super-resolution: obtain $\mathbf{x}$ with a higher spatial resolution than the nominal resolution of the detector.
2. BUT calculating $\mathbf{x}$ given $\mathbf{y}$ & $\mathbf{H}$ $\rightarrow$ An ill-posed inverse problem (i.e. No unique stable solution).

Bayesian approach

use **instrument model** and the **prior information** to have a better **map estimation**.

Outline

Bayesian approach

Bayes' rule:

$$p(\mathbf{x}|y) = \frac{p(y|\mathbf{x})p(\mathbf{x})}{p(y)}$$

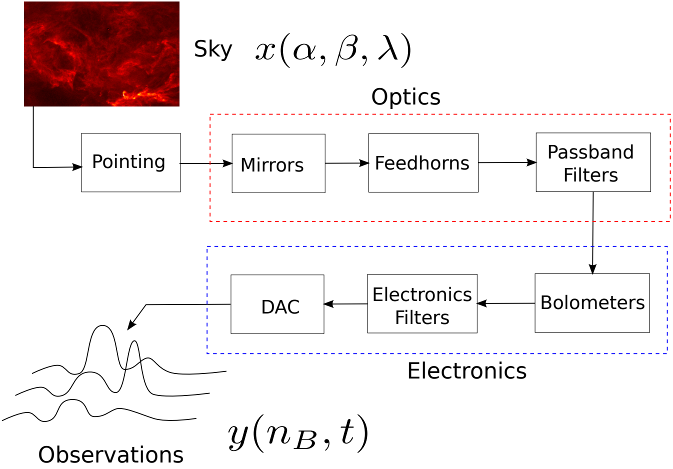
- $p(y|\mathbf{x})$: Likelihood (instrument and error models),
- $p(\mathbf{x})$: Sky prior (Smoothness: slow variation, Smooth + point sources),
- $p(y)$: Evidence (Normalising factor).

Estimation

- MAP: $\hat{\mathbf{x}} = \arg\max p(\mathbf{x}|y)$
- PM : $\hat{\mathbf{x}} = E\{\mathbf{x}\}_{p(\mathbf{x}|y)}$

Instrument Model

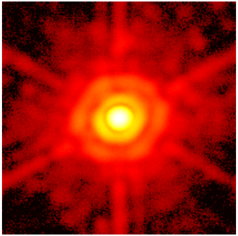
- Optics: Mirror, Feedhorns, Filters, ...
- Electronics: Bolometers, Electronic filters, ... (corrected in HIPE)



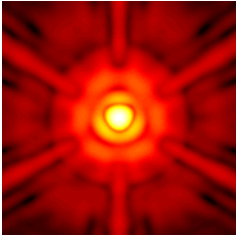
Optics

- Beam

Empiric

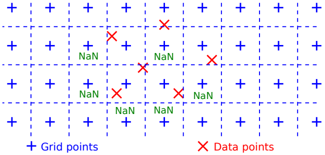


Simulated★

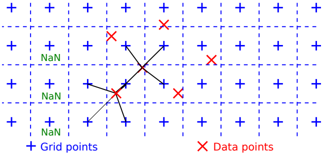


- Pointing

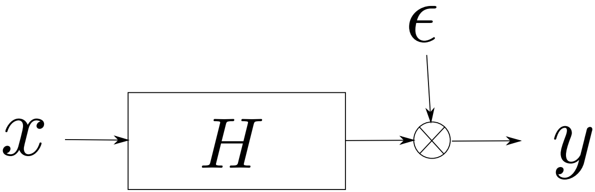
Nearest ★



Bilinear



Formulation

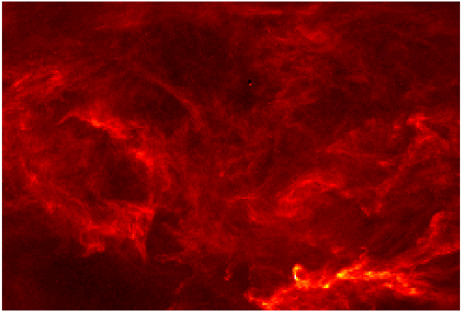


- $y(n_B, t)$: Observations (data)
- **H** : instrument model (Pointing + Optics)
- ϵ: Model error (White Gaussian with variance ${\rho_n}^{-1}$ and offset **o**)
- $x(\alpha, \beta)$: Sky (unknown)

Priors

- Extended source → smooth variations → Markovian model for the sky

$$p(\mathbf{x}|\rho_x) \propto \exp\left(-\frac{\rho_x}{2}\left[||D_\alpha \mathbf{x}||^2 + ||D_\beta \mathbf{x}||^2\right]\right)$$



- Offset: 4 options: none, constant/bolo/Obs, constant/bolo/Leg★, correlated/bolo/Leg, Under test

Joint estimation

Unsupervised approach

$$p(\mathbf{x}, \mathbf{o}, \rho_n, \rho_x|\mathbf{y}) \propto p(\mathbf{y}|\mathbf{x}, \mathbf{o}, \rho_n)p(\mathbf{x}|\rho_x)p(\mathbf{o})p(\rho_n)p(\rho_x)$$

$$\begin{aligned}\log\left(p(\mathbf{x}, \mathbf{o}, \rho_n, \rho_x|\mathbf{y})\right) = -0.5\Big(&\rho_n \left\|\mathbf{y} - \mathbf{H}(\mathbf{x}) - \mathbf{o}\right\|_2^2 + \rho_x \left(\left\|\mathbf{D}_\alpha \mathbf{x}\right\|_2^2 + \left\|\mathbf{D}_\beta \mathbf{x}\right\|_2^2\right) \\ &-N_y \log(\rho_n) + \frac{\rho_n}{\gamma_n} - (\phi_n - 1)\log(\rho_n) \\ &- N_s \log(\rho_x) + \frac{\rho_x}{\gamma_s} - (\phi_s - 1)\log(\rho_x) + \rho_o \left\|\mathbf{o}\right\|_2^2 + cte\Big)\end{aligned}$$

Estimator

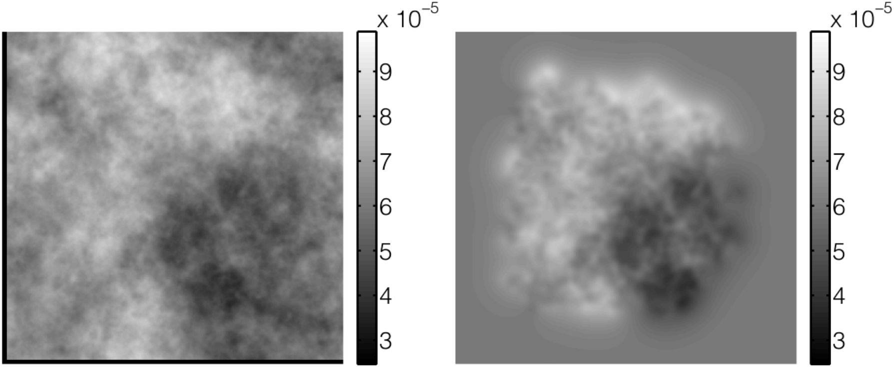
- Deterministic: Variational Bayesian Approach (VBA).
- Stochastic: Monte Carlo Markov Chains (MCMC).

HIPE plug-in

- Website: `http://www.ias.u-psud.fr/supreme/home.php`

- Install MCR (Matlab Compiler Runtime)
- Install plug-in
- Use with ObsIDs or any L1 DataPool
- change parameters if different from default value

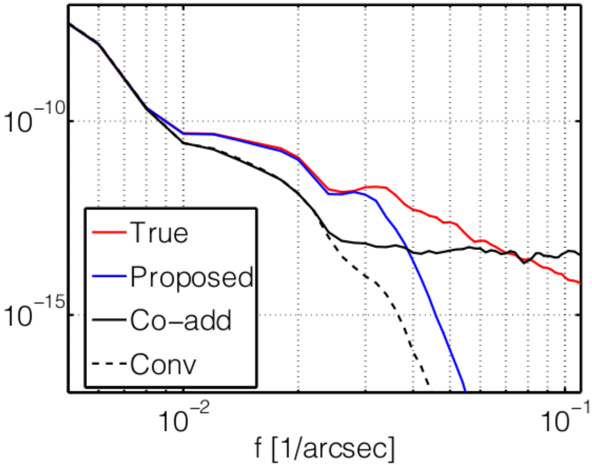
Simulation



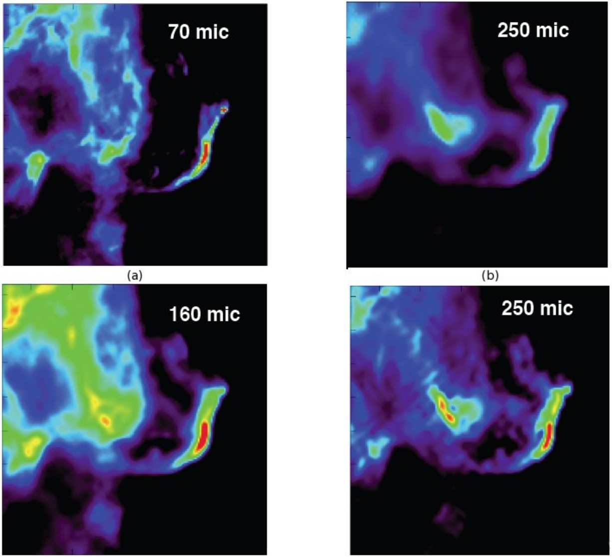
(a) True map (b) Proposed map

Relative error $= 4\%$

Simulation

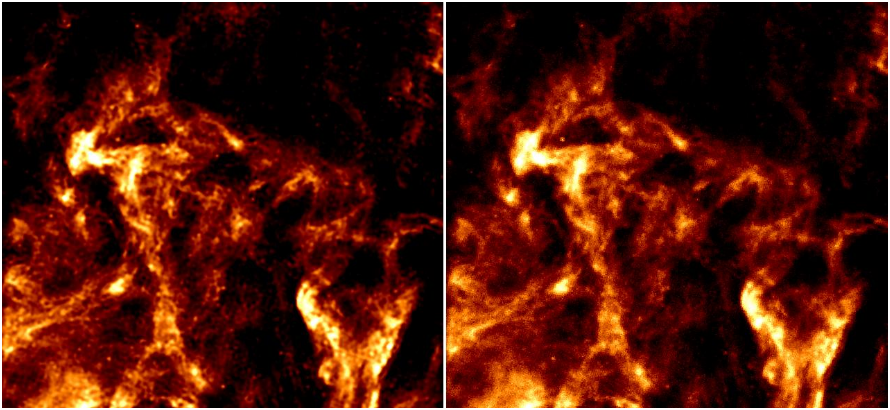


Application (Horse Head)

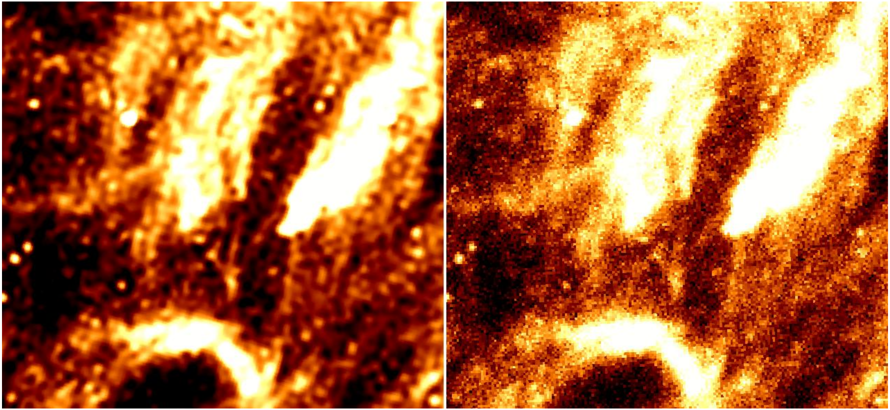


(a) (b) (c) (d)

Application (Polaris)

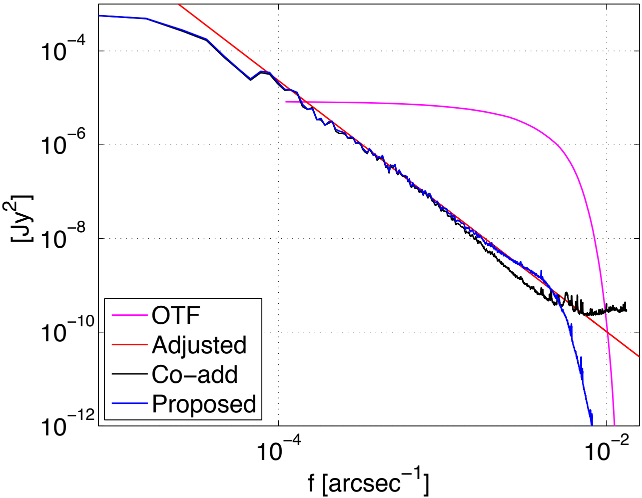


Application (Polaris)



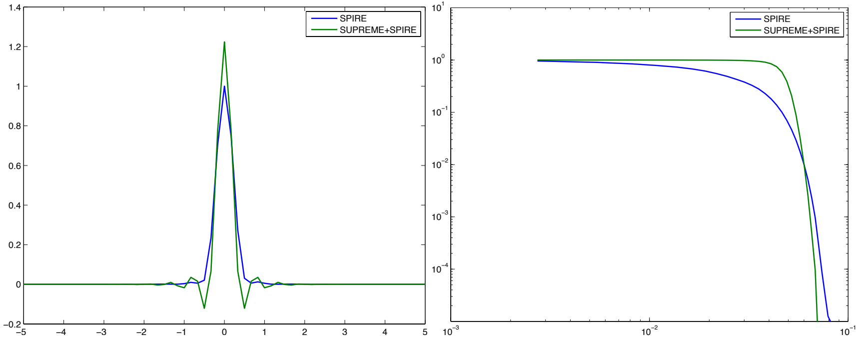
Power Spectrum Density

Polaris



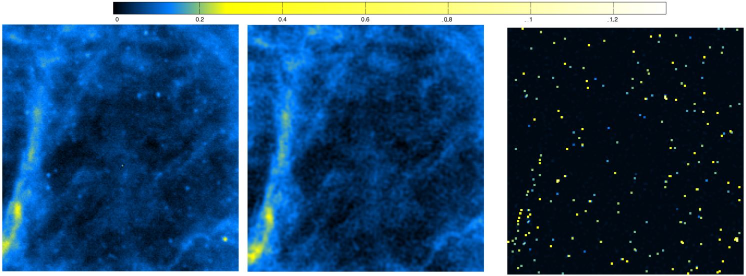
Equivalent Beam

Polaris

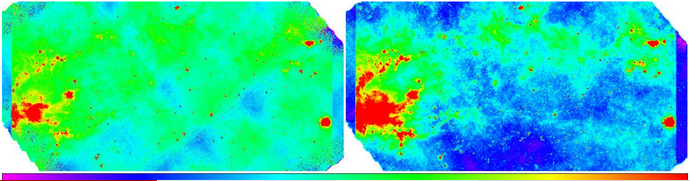


Enhancements

1. Joint beam width estimation in Orieux et al 2013 (MCMC based) [OGRA13]
2. Mixture of extended and point sources (SUPREMEX) in Ayasso e al 2012[ARA12a]



3. Drift estimation (under test)



Future

Many things are still coming:

- Under test: drift model.
- Portability to other instruments, telescopes (Planck, ...).
- Enhanced instrument model:
  - bolometers gains?,
  - beams per bolometer? ,
  - electrical filtre?
- Cautions
  - Not suitable for point sources (specially strong ones): use SUPREMEX instead.
  - Stationary model,
  - Automatic estimation can go wrong if model is not respected $\rightarrow$ use Manual settings

Conclusions

Bayesian super-resolution mapmaking method with several novelties,

- 3x resolution gain
- Interval of confidence available out of the box.
- Unsupervised approach: automatic estimation for the methods hyperparameters
- Accounting for theoretical and empirical instrument models.
- Mask friendly
- Controlled equivalent beam (SPIRE+SUPREME).
- HIPE plugin available: `http://www.ias.u-psud.fr/supreme/home.php`
- Also available for FTS (plugin coming soon)

References

- H. Ayasso, T. Rodet, and A. Abergel.
  A variational bayesian approach for unsupervised superresolution using mixture models of point and smooth sources applied to astrophysical map-making.
  Inverse Problems, 28(12):125005, 2012.
- Hacheme Ayasso, Thomas Rodet, and Alain Abergel.
  A GRADIENT-LIKE VARIATIONAL BAYESIAN APPROACH FOR UNSUPERVISED EXTENDED EMISSION MAP-MAKING FROM SPIRE/HERSCHEL DATA.
  10 INSU, July 2012.
- F. Orieux, J.F. Giovannelli, T. Rodet, A. Abergel, H. Ayasso, and M. Husson.
  Super-resolution in map-making based on a physical instrument model and regularized inversion. application to spire/herschel.
  Astronomy & Astrophysics, 539:16, 2012.
- Orieux, F., Giovannelli, J. F., Rodet, T., and Abergel, A.
  Estimating hyperparameters and instrument parameters in regularized inversion illustration for herschel:spire map making.
  A&A, 549:A83, 2013.