FILTER DESIGN: application to the detection of compact sources in CMB maps

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I. Methodology

- Resolved compact sources
- Filter: Scalar, Vector, Matrix
- Criteria for detection
- Parameter estimation

II. Applications

- Toy Model
- Planck simulations

Techniques for resolved sources:

- Component separation
- Bayesian approach
- Fusion
- Filters

THE MICROWAVE SKY:

CMB + contaminants + noise

Contaminants:

- DIFFUSE EMISSION:

Galactic emission (synchrotron, free-free, dust)

- COMPACT SOURCES:

➢ Extragalactic point sources

➢ Clusters of galaxies (Thermal and kinematic Sunyaev-Zeldovich effect)

Extragalactic point sources

- Two main populations:
  - Radio sources (below ~ 200 GHz)

    Toffolatti et al. 1998, de Zotti et al. 2005
  - Infrared sources (above ~ 200 GHz)

    Guiderdoni et al. 1998, Granato et al. 2001
- Properties:
  - Point-like objects ⇨ beam profile
  - Different frequency dependence for each source
  - localized objects

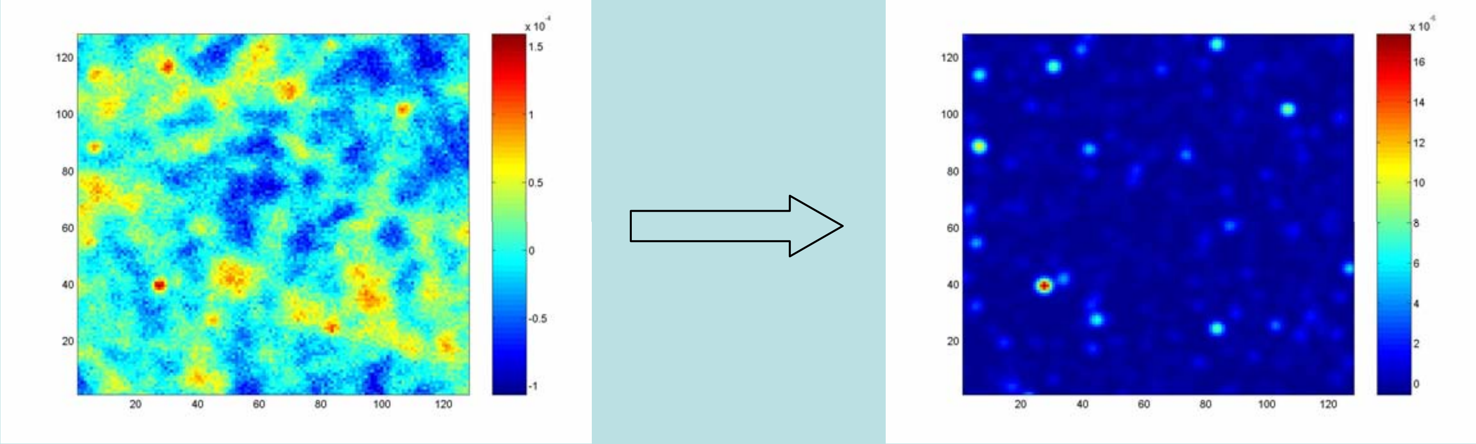
⇨ **not suited for global separation techniques!**

Objectives:

1. *To detect as many compact sources as possible, with as fewer false detections as possible*

2. *To estimate with the lowest error parameters (position, flux, spectral index, etc) of the sources*

in order to: Clean CMB maps (C_l, primeval non-Gaussianity,...)
Do extragalactic science (catalogs,...)



MATCHED FILTERS

- ***Standard Matched Filter (MF)***

  Single image → Single image

- ***Matched multifilter (MMF) or Multifrequency filter (MFF)***

  N images → Single image

- ***Matched Matrix filter (MMXF)***

  N images → N images

1. SCALAR Filter

$$d(x) = A\tau(x) + n(x), \qquad 1 image$$

$$d_f(x) = \int dy\, \psi(y-x) d(x), \quad 1 image$$

1) $\langle d_f(0) \rangle = A$ 2) σ_f Minimum

$$\hat{\psi}(q) \propto \frac{\hat{\tau}(q)}{P(q)}$$

2. VECTOR Filter

$$d_i(x) = f_i A \tau_i(x) + n_i(x), \quad f_i : freq, \quad n \ images$$

$$d_f(x) = \int dy \sum_i \psi_i(y - x)\, d_i(x), \qquad 1 \ image$$

$$1) \ \langle d_f(0) \rangle = A \qquad 2) \ \sigma_{d_f} \ \ Minimum$$

$$\tau = \left(f_i \hat{\tau}_i \right), \ P = \left(P_{ij} \right): \qquad \hat{\psi}(q) = \left(\hat{\psi}_i \right) = P^{-1} \tau$$

Herranz, Sanz et al. 2002, *MN* 336, 1057

3. MATRIX Filter

$$d_i(x) = A_i \tau_i(x) + n_i(x) \qquad i = 1, \ldots, n \quad images$$

$$d_{if}(x) = \int dy \sum_j \psi_{ij}(x-y) d_j(y) \qquad n \, images$$

$$1) \quad \langle d_{if}(0) \rangle = A_i \qquad 2) \, \sigma_{if} \quad MINIMUM$$

$$F = \left(F_{ij} = \lambda_{ij} \hat{\tau}_j \right), \; P = \left(P_{ij} \right), H = \left(H_{ij} = \int dq \, \hat{\tau}_i \hat{\tau}_j P_{ij}^{-1} \right),$$

$$\lambda = \left(\lambda_{ij} \right) = H^{-1}, \qquad \hat{\psi}(q) = \left(\hat{\psi}_{ij} \right) = FP^{-1}$$

Herranz, Sanz 2008, *J.S.T.S.P.* 20

TOY MODEL

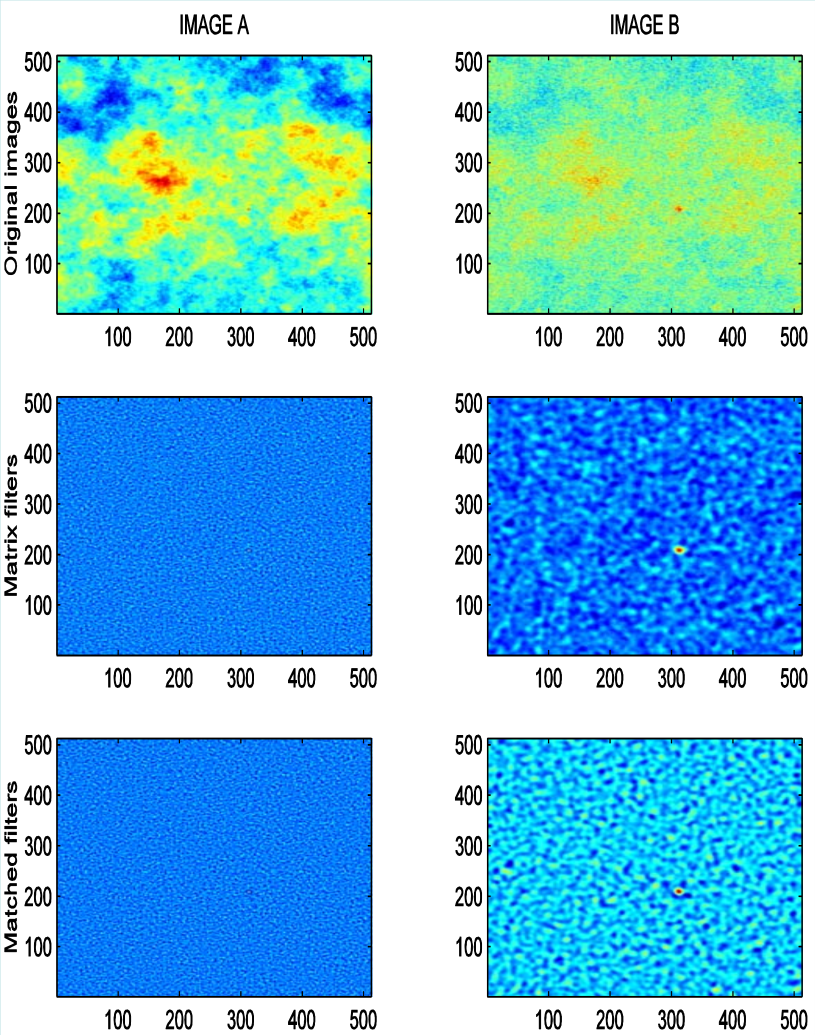
- 2 IMAGES A, B:
- Color noise:

$$\begin{cases} \sigma_A = \sigma_B = 1, \quad \xi_{AB} = 0.67 \\ A: P_A = N_A q^{-2.5}, \quad B: P_B = N_B q^{-0.5} + \frac{N_A}{2} q^{-2.5} \end{cases}$$

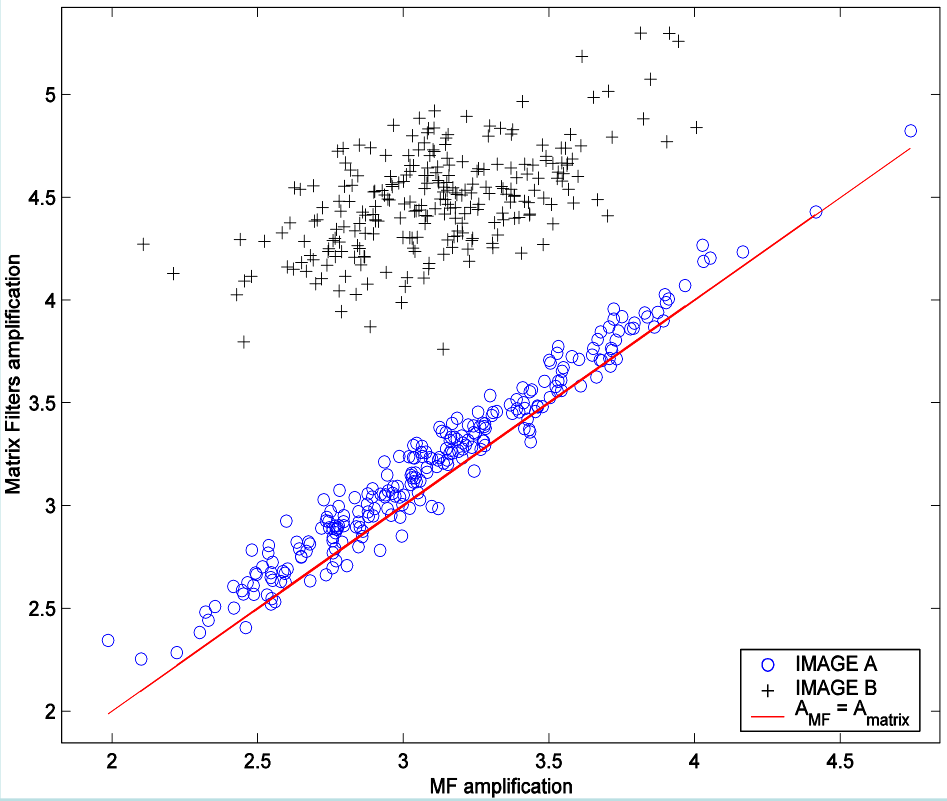
- Point Source:

$$\begin{cases} uniform\ \ dist. \quad in \quad [2.75, 3.75] \\ FWHM_A = 3.33 pix, \quad FWHM_B = 10 pix \end{cases}$$

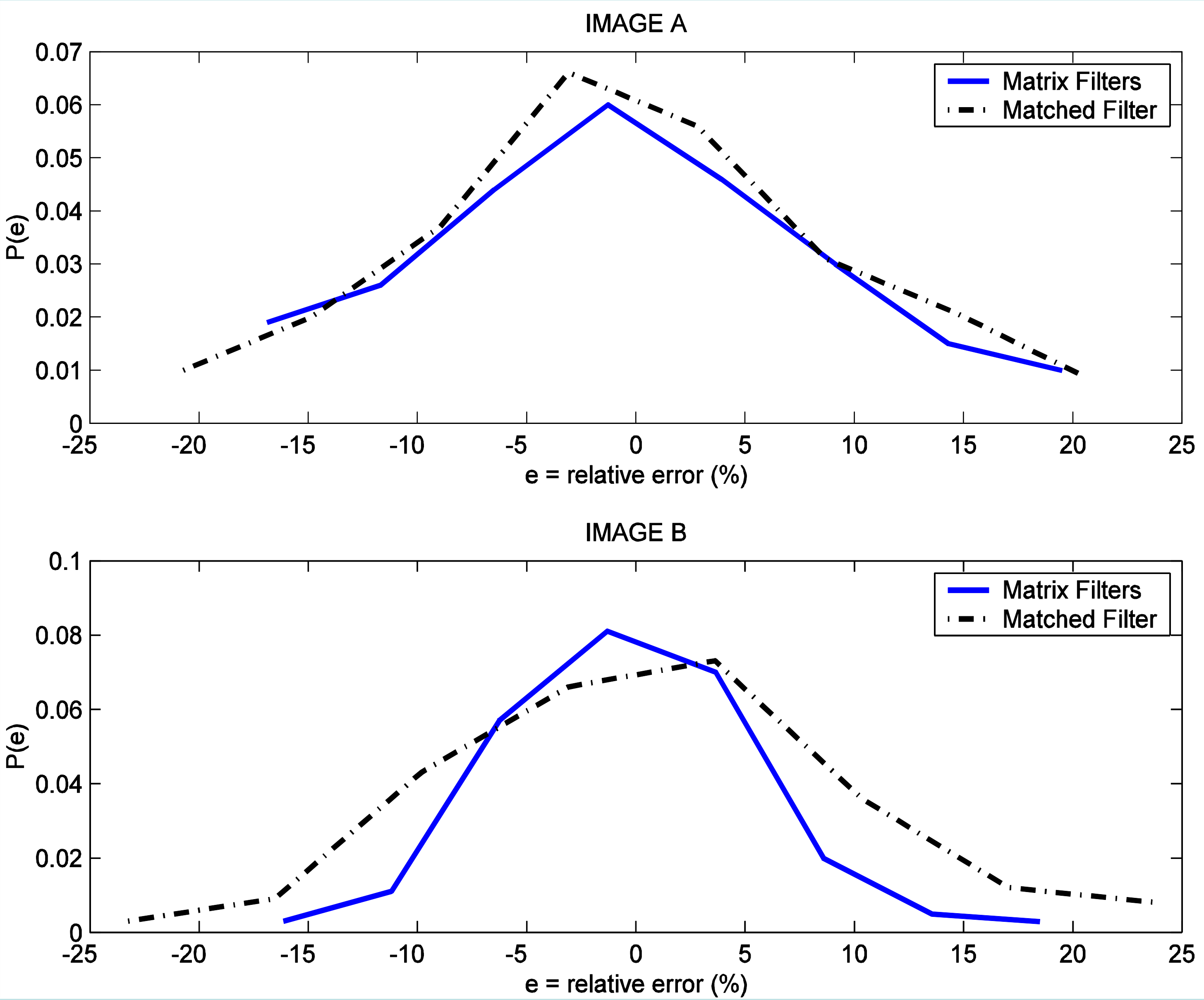
TOY MODEL



250 simulations



Relative Errors



RESULTS: MMXF vs. MF

- GAIN:

  Image A: gain is small (3%),

  Image B: gain is high (45%)

- Relative ERROR in Flux:

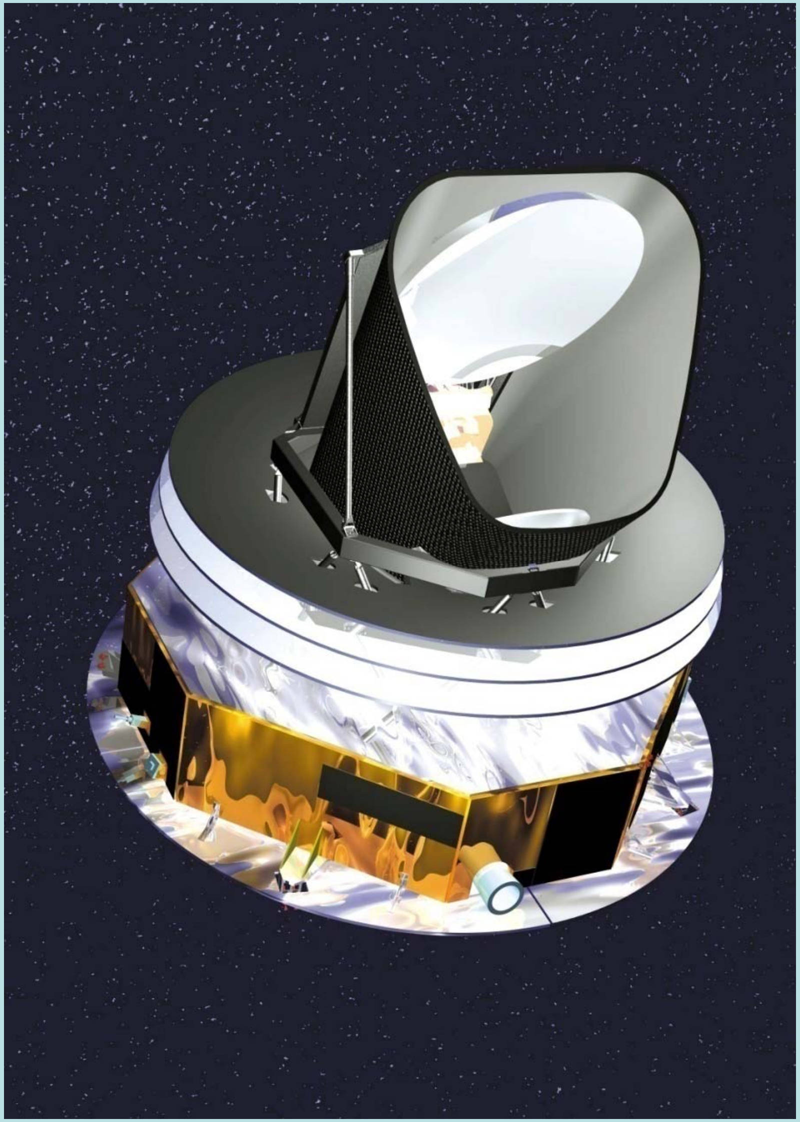
  Image A: approx. the same,

  Image B: MF spreads more.

DETECTION of POINT SOURCES on Planck simulations

D. Herranz, J. L. Sanz (2008)

The Planck Mission



- It is a satellite from ESA (to be launched in 2009) that will measure over the whole sky the CMB signal (intensity and polarization) with unprecedented resolution and sensitivity

- **Multifrequency coverage (9 channels from 30-857 GHz)**

- **High angular resolution (5 – 33 arcminutes)**

2. **Simulations**

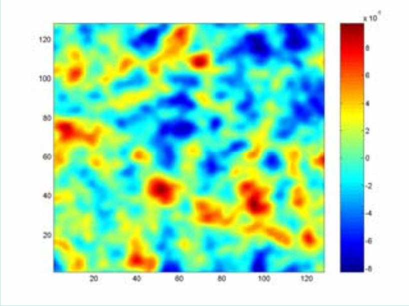
- **Foregrounds: Planck Reference Sky**
  - **Thermal Dust**
  - **Synchrotron**
  - **Free-Free**
  - **SZ Clusters**

- **CMB**
- **Point Sources**: de Zotti et al. (2005)
- **Instrumental Noise**

Flat patch of the sky. This are the contributions in one field:

Convolved With the Instrument Antenna

Cosmic Microwave Background Radiation



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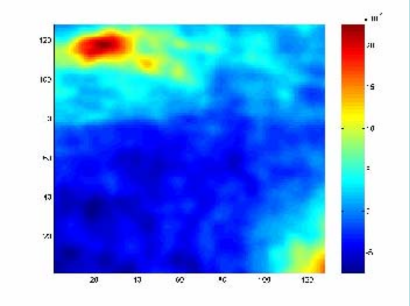
Foregrounds Emission from the galaxy



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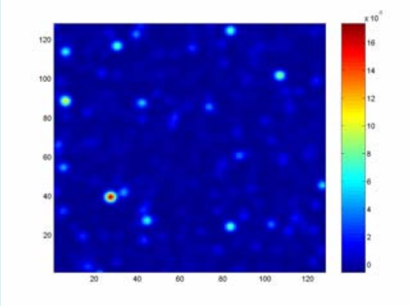
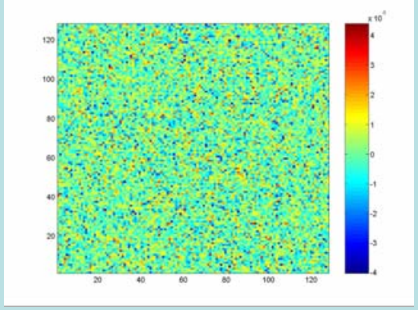
Point Source Galaxies



Instrumental noise

+



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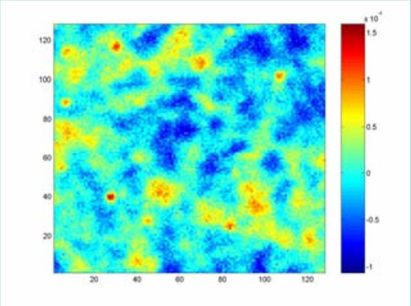


HOW?

Using MMXF !

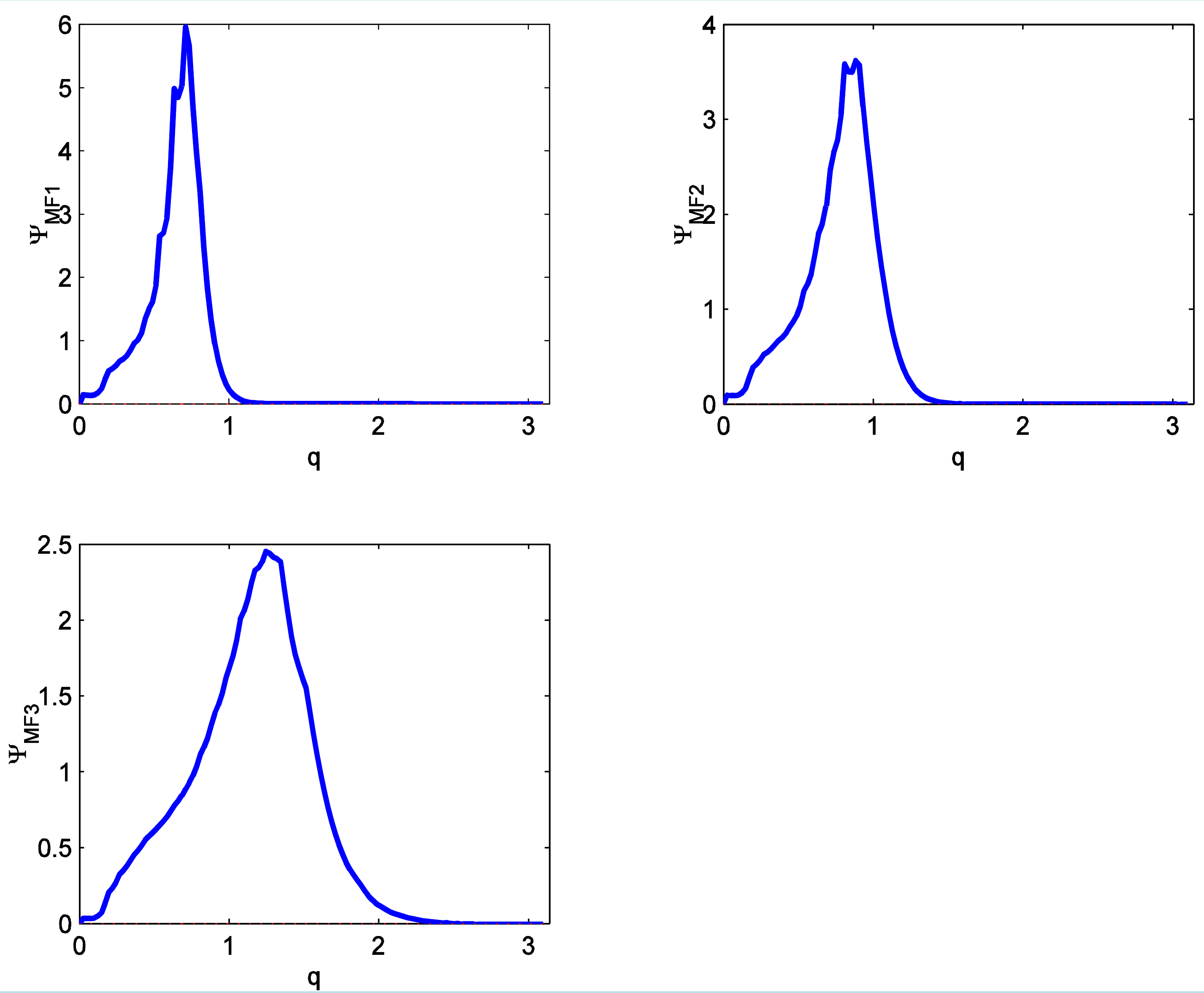
The Simulation:

Freq	Im Size(pix)	FWHM (‘)	Pix Size (‘)
• 30 GHz:	512x512	33.0	1.71
• 44 GHz:	512x512	24.0	1.71
• 70 GHz:	512x512	14.0	1.71

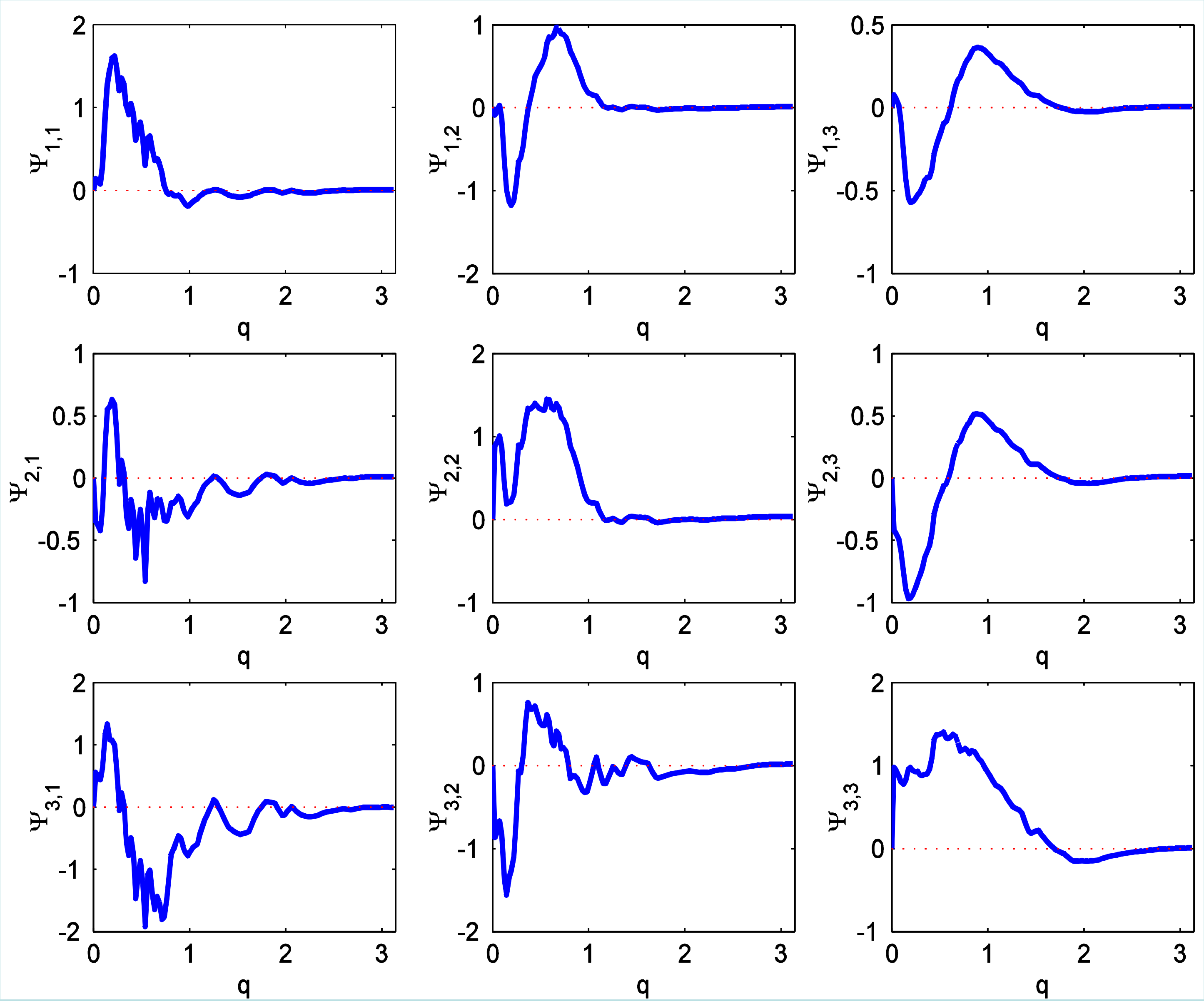
- Region of the sky centered at the GNP,

- 14.66x14.66 degrees,
- 512x512 pix of size 1.71x1.71 arcmin

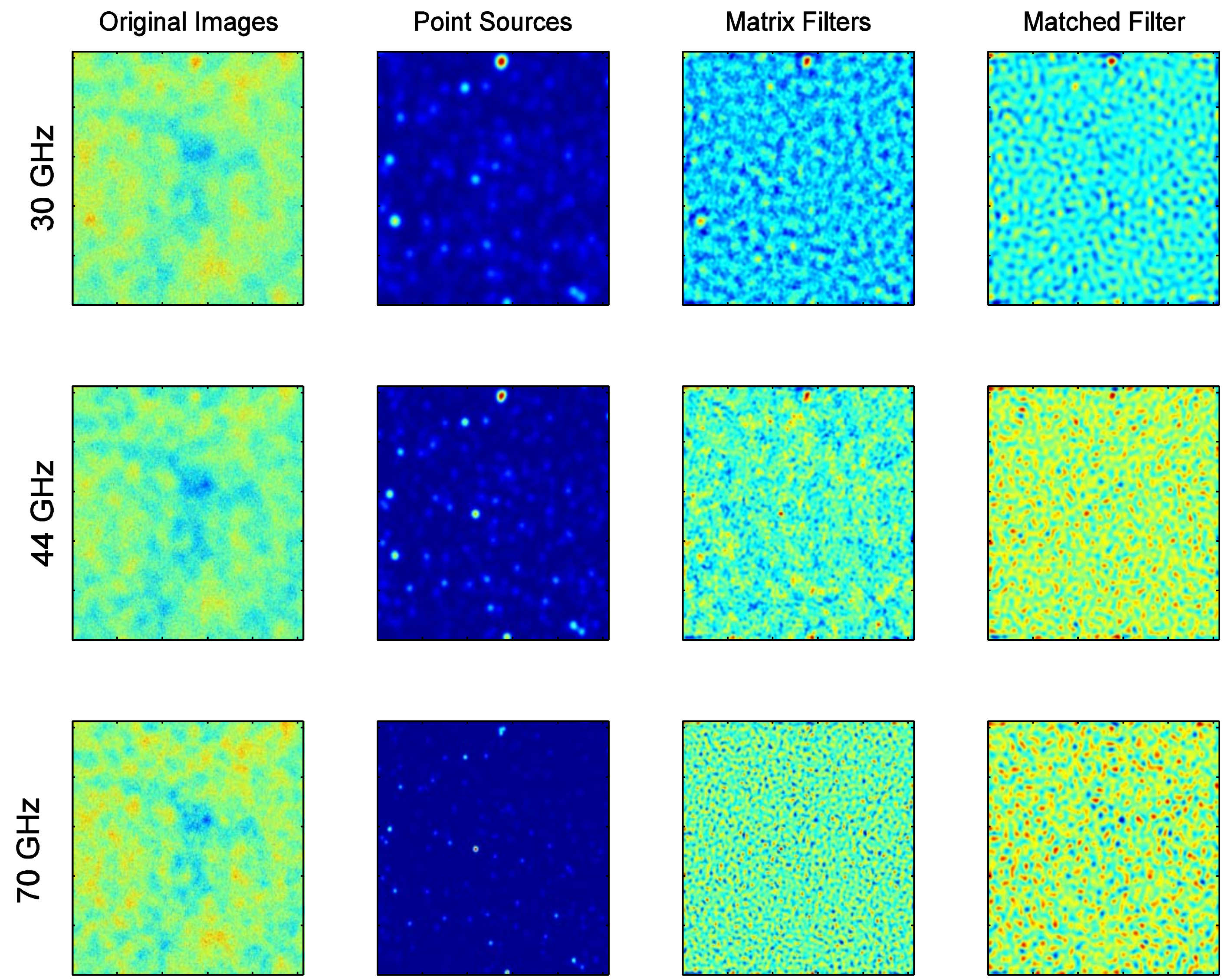
Matched Filter

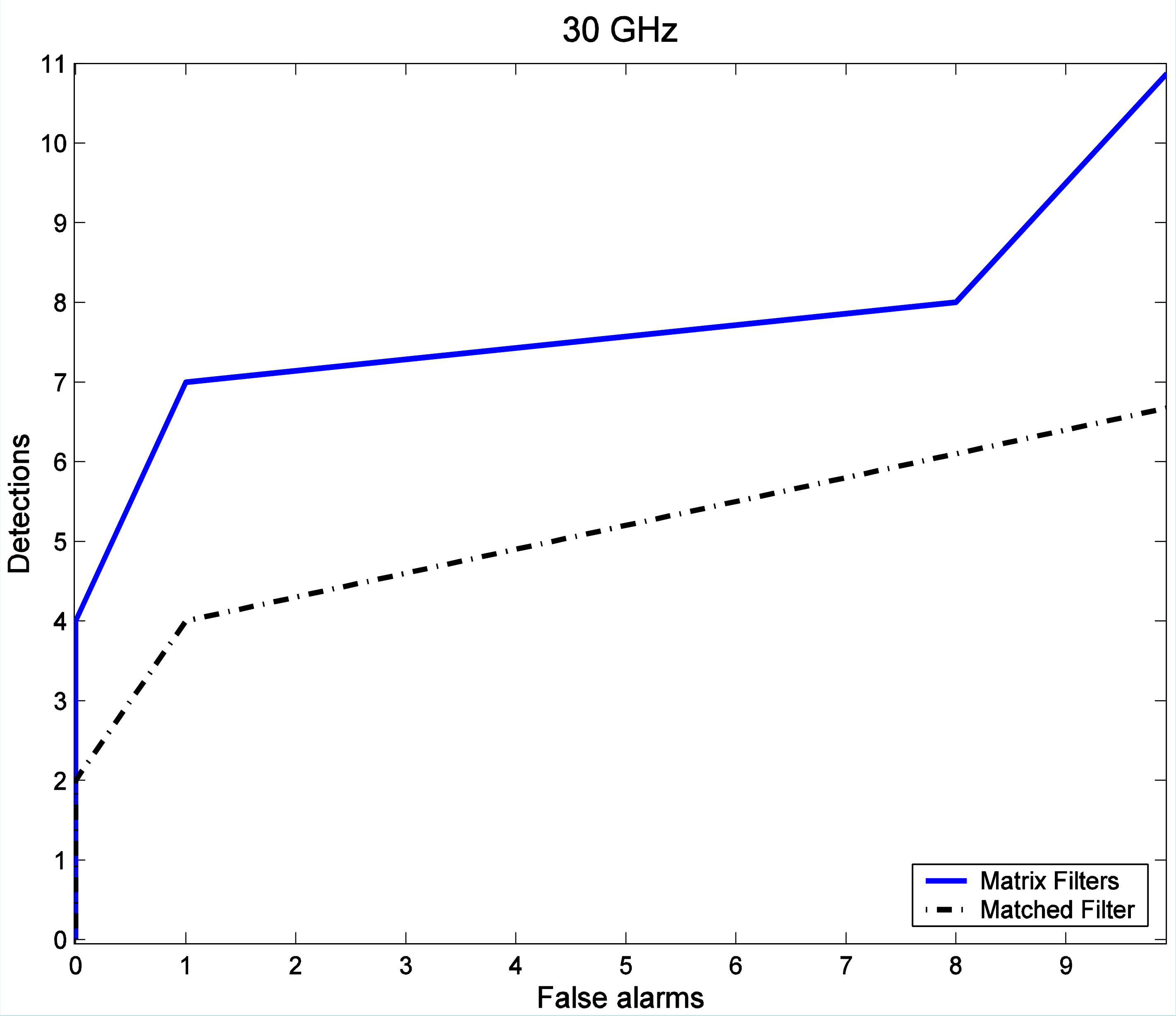


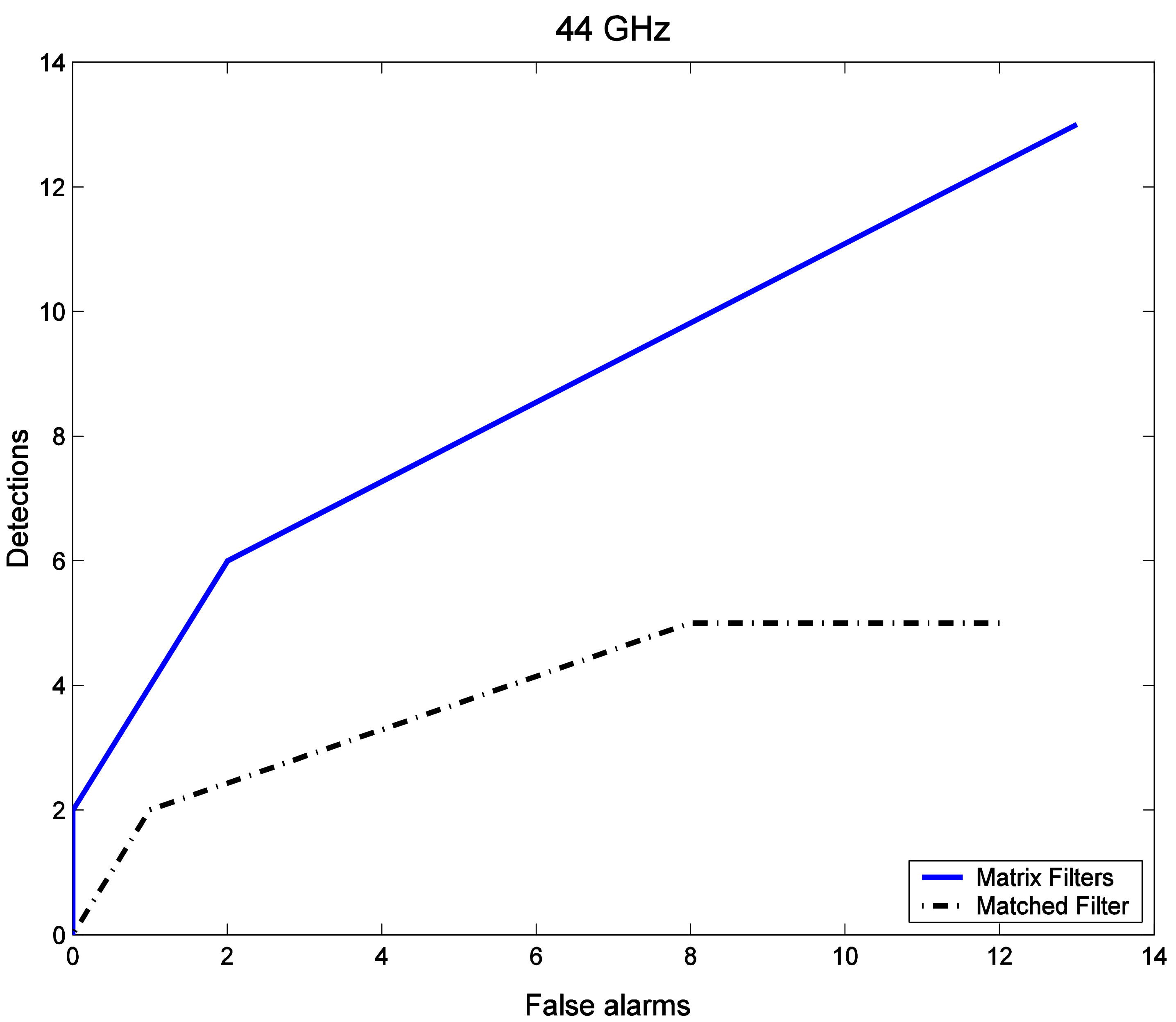
Matrix Filter



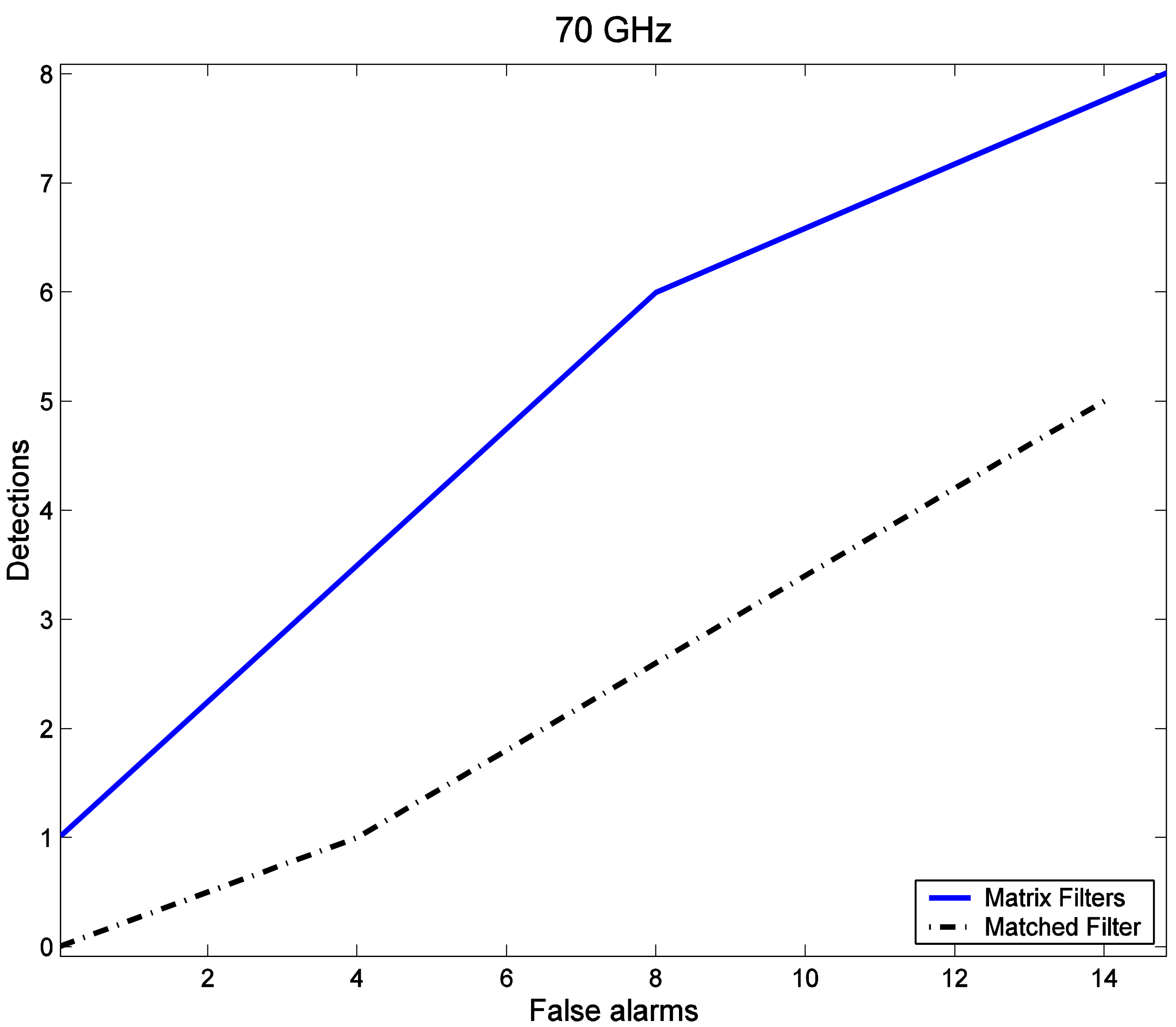
Planck Simulation




30 GHz
Detections
False alarms
0
1
2
3
4
5
6
7
8
9
10
11
0
1
2
3
4
5
6
7
8
9
Matrix Filters
Matched Filter



44 GHz
Detections
False alarms
0
2
4
6
8
10
12
14
0
2
4
6
8
10
12
14
Matrix Filters
Matched Filter


70 GHz
Detections
False alarms
0
1
2
3
4
5
6
7
8
2
4
6
8
10
12
14
Matrix Filters
Matched Filter

Conclusions

- We have compared the performance of two filters when dealing with the detection of point sources in CMB astronomy (MF on single images and MMXF).

1) Toy model:

better performance (Gain and Flux error) of MMXF vs. MF on two correlated images.

2) Planck simulations:

- We have considered simulations with the Planck characteristics for 3 Planck frequencies (30, 44, 70 GHz).

- We have found that the MMXF outperform the MF:
  - higher n. of detections for a fixed n. of false alarms.
  - Completeness is higher.