Postdoc seminar
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# From indoor localization to galaxy cluster detection

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# Background and present

- PhD and postdoc at the Data Processing and Simulation Group, Universidad Politécnica de Madrid (Spain)
  - Indoor localization


- Postdoc at SAp, CEA
  - Detection of galaxy clusters

# Outline

- Indoor localization


- Detection of galaxy clusters

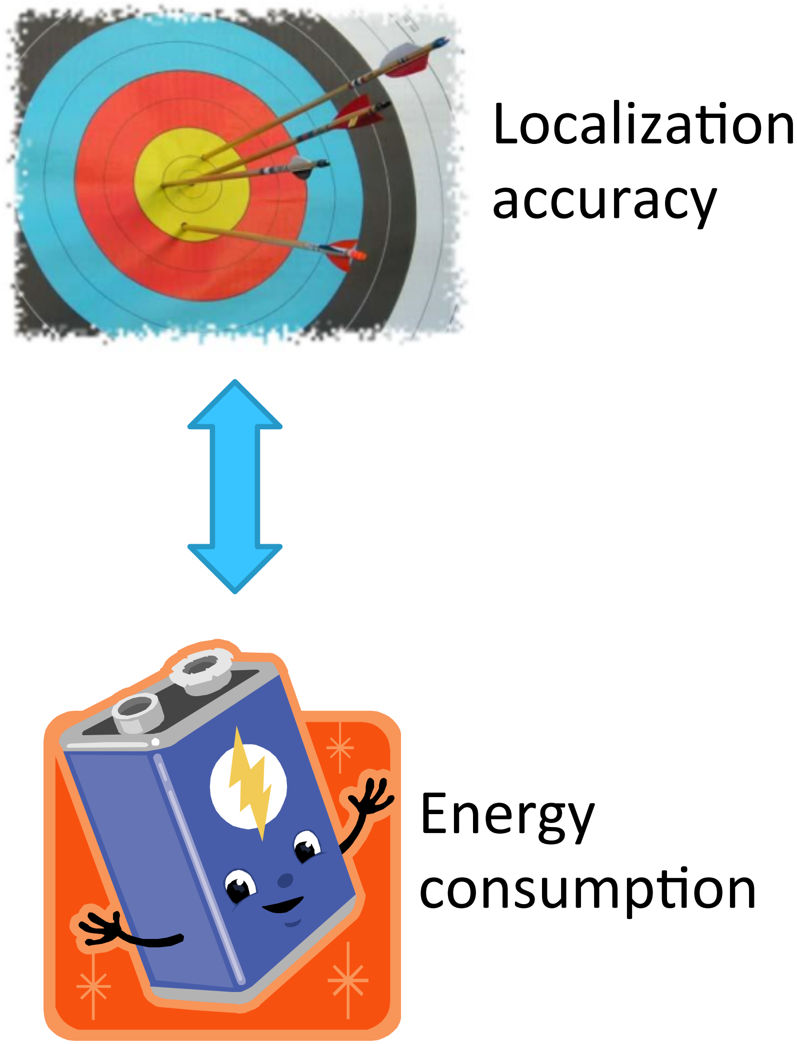
# Introduction

- Localization: Estimate the position of an object or person
- Localization and tracking of people and objects is fundamental for numerous applications
  - Emergency management
  - Domotic control
  - Ambient-assisted living
  - Augmented reality



# Localization technologies

- **Outdoor** loc. technologies
  - GPS
  - Cellular
- **Indoor** loc. technologies
  - Radio
  - Inertial sensors
  - Ultrasound
  - Infrared
  - Computer vision
  - Pressure sensors
  - Electromagnetic sensing

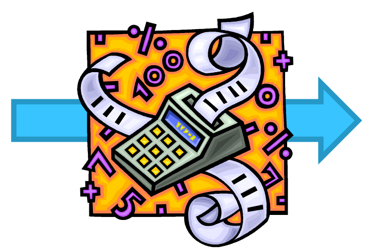


# Radio-localization

- Typical deployment:
  - Reference nodes at know (fixed) positions
  - Mobile nodes whose position we want to calculate
- Communication phase: Measure some parameter of the radio signal
  - Connectivity (signal/no signal)
  - TOA/TDOA
  - AOA
  - RSS

- Processing phase

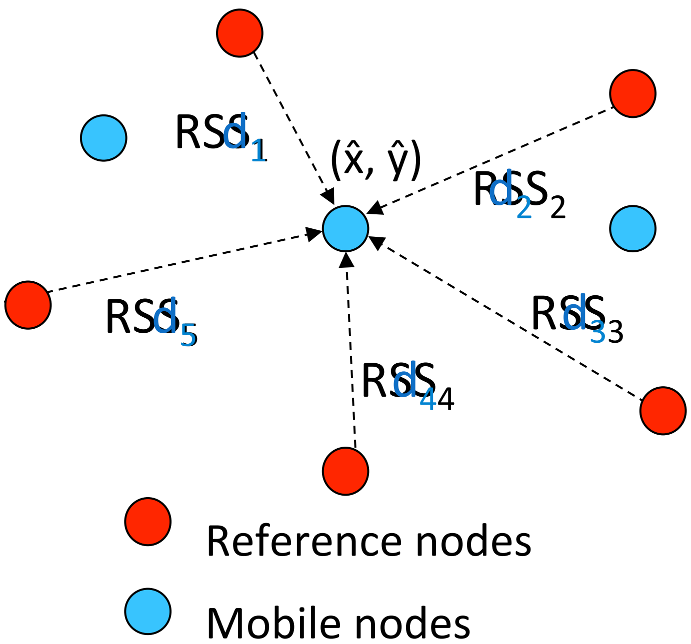
Measurements

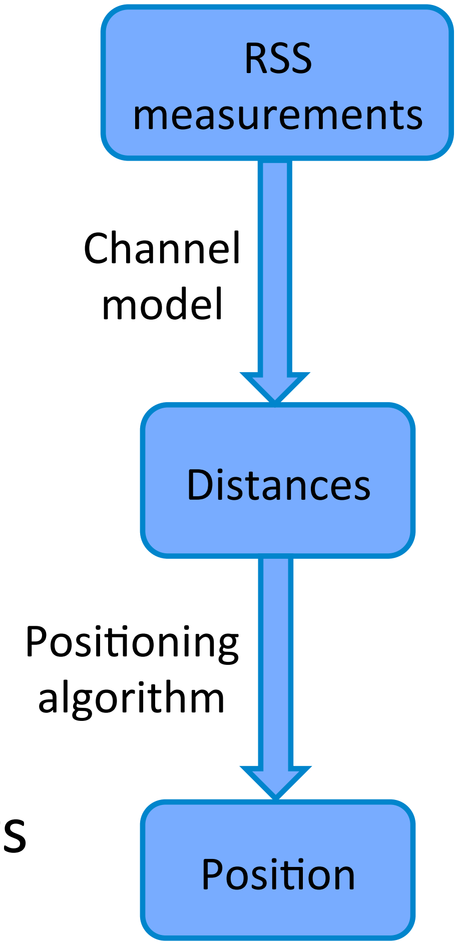


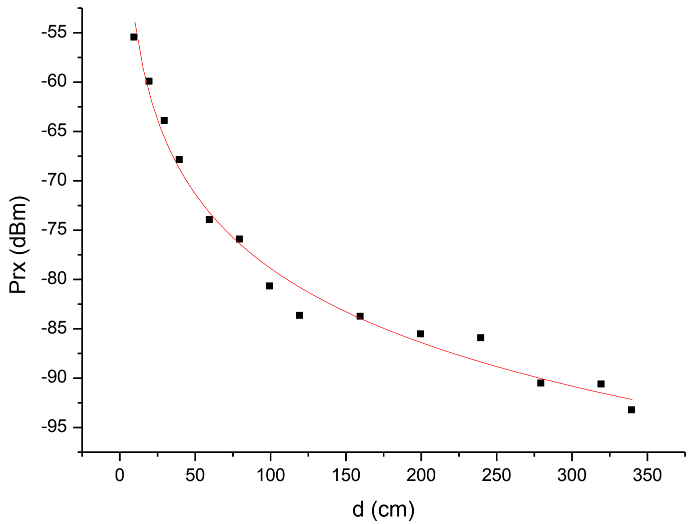
Position

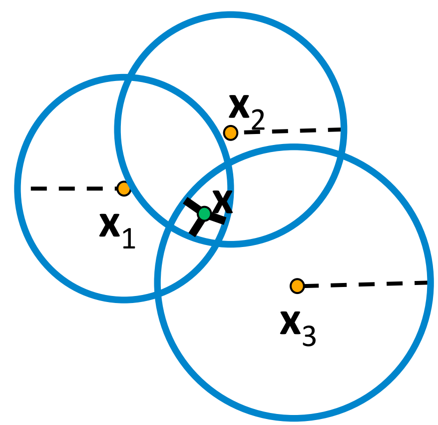
# RSS-based localization system

- Channel modeling approach:



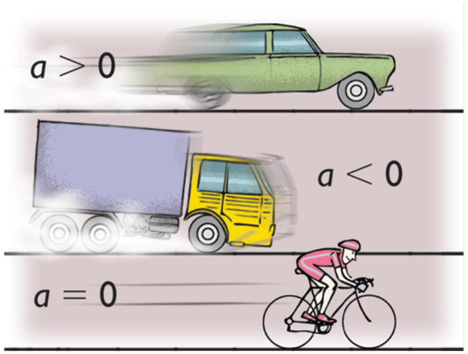




- Accuracy: 2-4 meters

# Inertial sensors

- What are inertial sensors?
  - Accelerometers
    (measure acceleration)

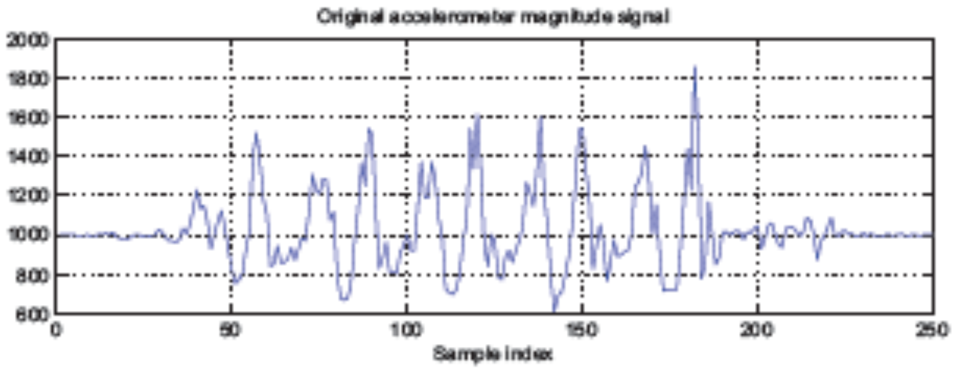



  - Gyroscopes
    (measure angular speed)

- Recently lightweight and small
  - Thanks to MEMS technology
  - Used in mobile phones, smartphones, etc.

# Inertial tracking systems

- Typical deployment:
  - The person/object to be tracked carries the inertial sensors
  - No fixed infrastructure is needed
- Localization is done via dead reckoning: calculating current position from
  - a previous position/speed
  - measurements collected by the sensors




- Problem: Drift: position error grows with time

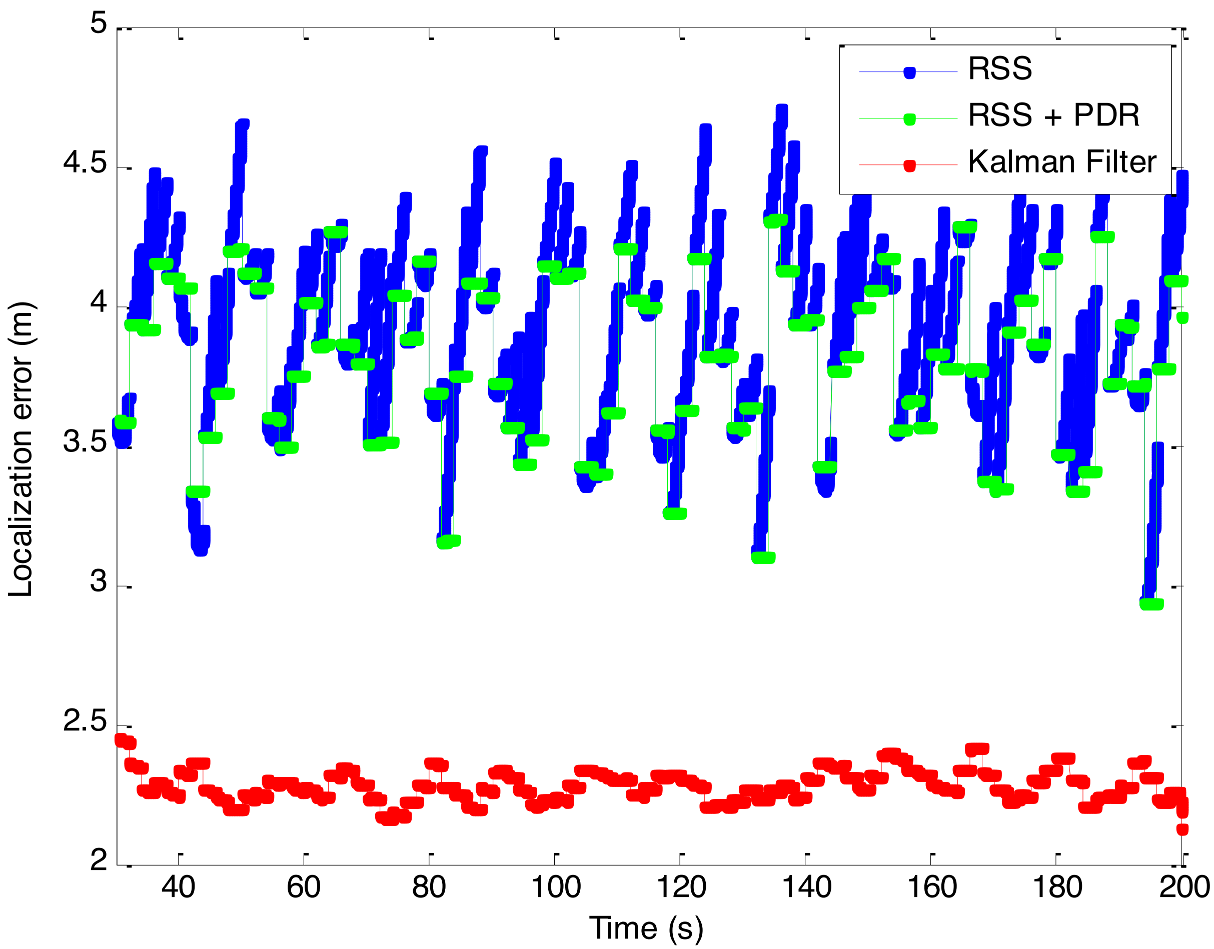
# Hybrid localization systems

- RSS-based localization system
  - Medium accuracy
  - constant with time
- Inertial tracking system
  - Good accuracy
  - growing with time
- Others …

+

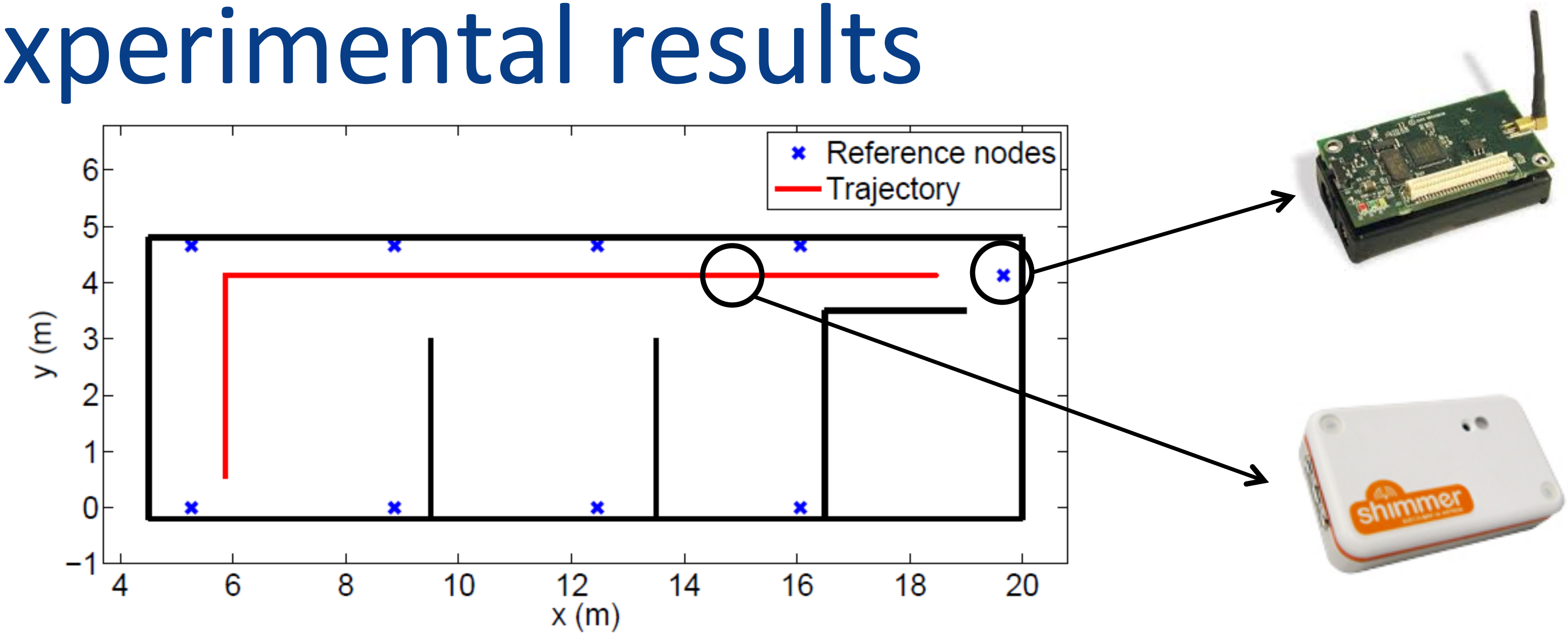
- Fusion algorithm
  - Kalman filter
  - Particle filter
  - …

# Simulation results




9 reference nodes
400 $m^2$ area

# Experimental results




Average localization error

| User | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| RSS | 3.31 | 2.68 | 2.48 | 3.83 | 2.59 | 2.82 | 3.72 | 2.70 |
| RSS + PDR | 3.05 | 2.54 | 2.32 | 3.60 | 2.47 | 2.48 | 3.42 | 2.61 |
| KF | 2.39 | 2.26 | 1.64 | 2.92 | 2.30 | 2.22 | 2.63 | 2.22 |

Maximum localization error

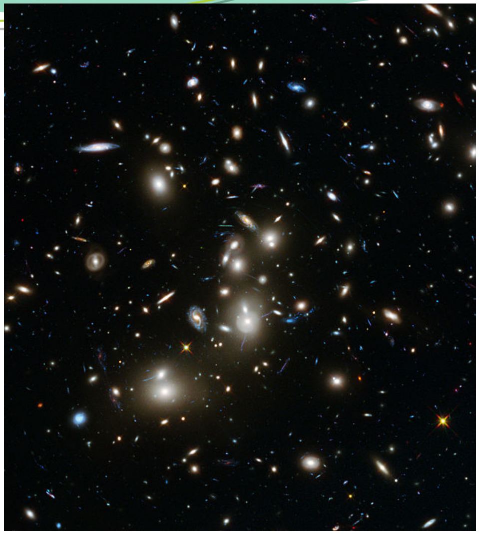
| User | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| RSS | 11.06 | 6.45 | 8.03 | 10.60 | 6.58 | 5.98 | 7.75 | 5.87 |
| RSS + PDR | 11.17 | 6.20 | 8.03 | 9.93 | 6.33 | 5.97 | 7.67 | 5.61 |
| KF | 3.91 | 4.36 | 4.02 | 4.30 | 4.65 | 4.33 | 3.92 | 4.62 |

# Outline

- Indoor localization


- Detection of galaxy clusters

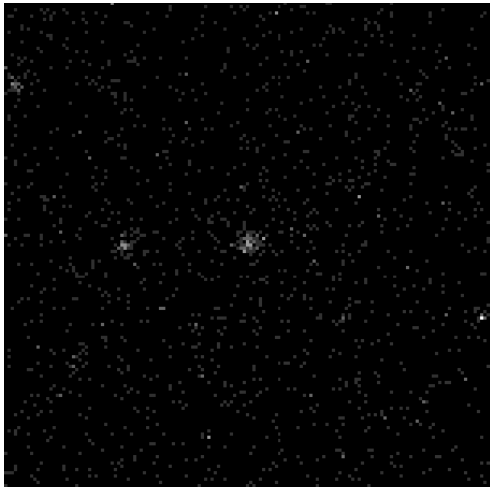
# Galaxy clusters

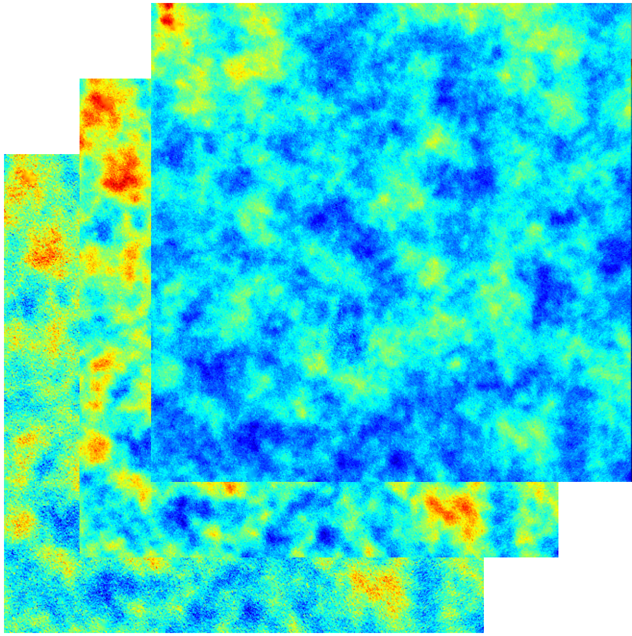


- Galaxy clusters:
  - 100s/1000s galaxies bound by gravity
  - Hot ionized gas
  - Dark matter
- The history of structure formation in the Universe depends on the cosmology -> studying cluster samples at different redshifts can constrain cosmological parameters
- Goal: build a sample of massive clusters up to z~1

# Detection of galaxy clusters

- The hot ionized gas of the inter-cluster medium
  - emits thermal radiation in the X-ray band
  - distorts the cosmic microwave radiation via the Sunyaev-Zeldovich effect
- We are developing an algorithm to combine these two complementary sources of information
  - improve the cluster detection rate
  - reduce the number of false detections
- SZ cluster detection is undertaken via a Matched Multi-Filter (MMF)*

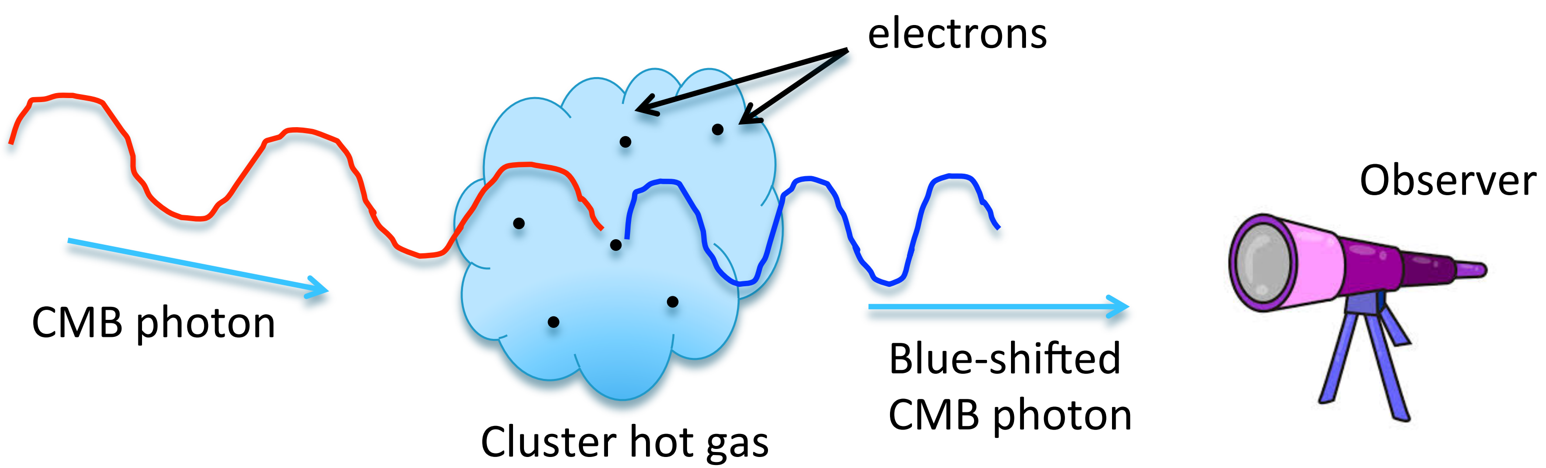




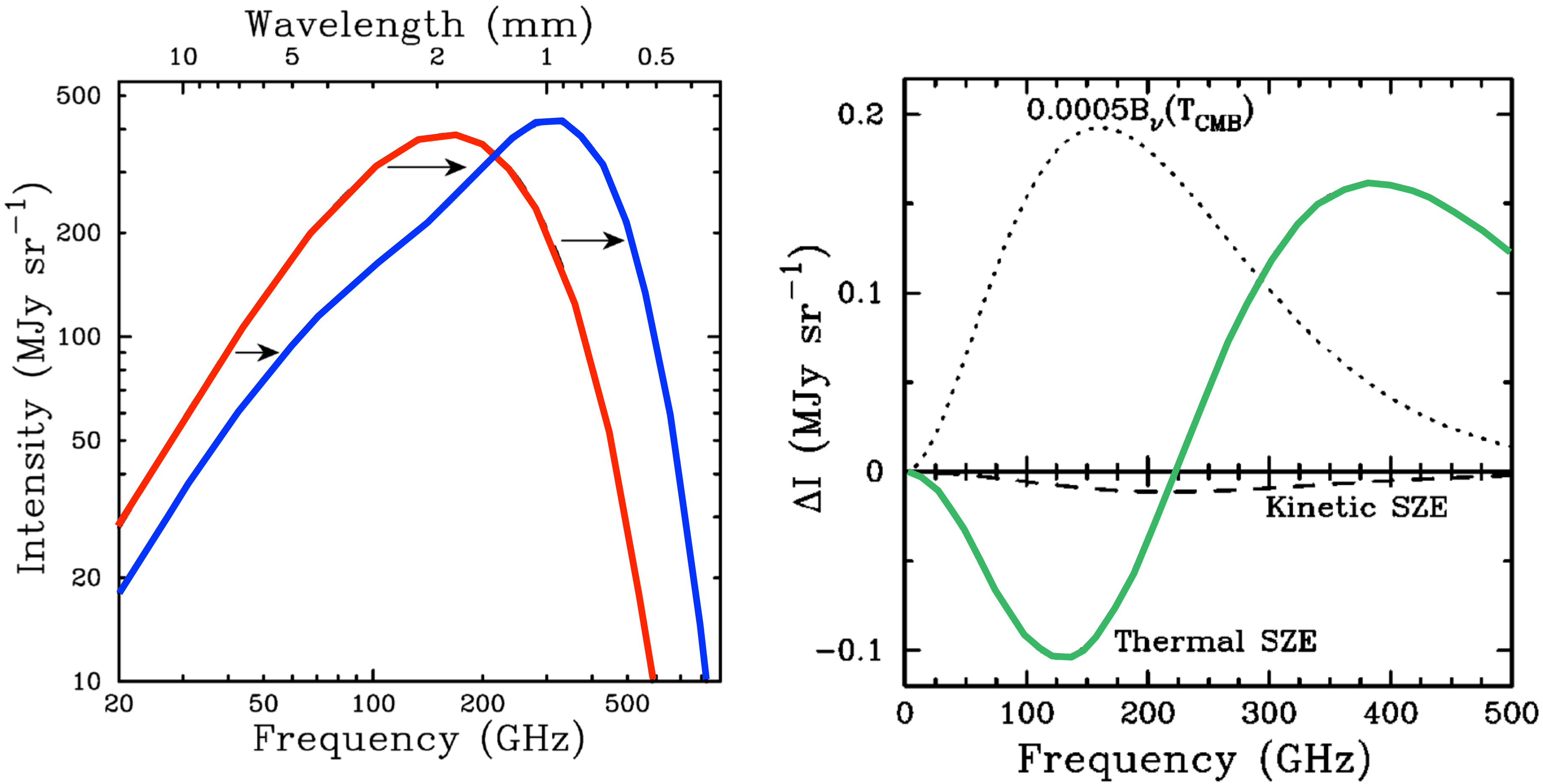
* Melin et al. 2006

# The SZ effect

- The SZ effect is caused by the hot gas in galaxy clusters
- CMB photons gain energy when they interact with the electrons of the gas



# Spectral distortion




Figures from Carlstrom 2002

# Spectral distortion

- Universal form
- Amplitude given by the Compton y parameter (integral of the gas pressure along the line-of-sight)

Compton y parameter

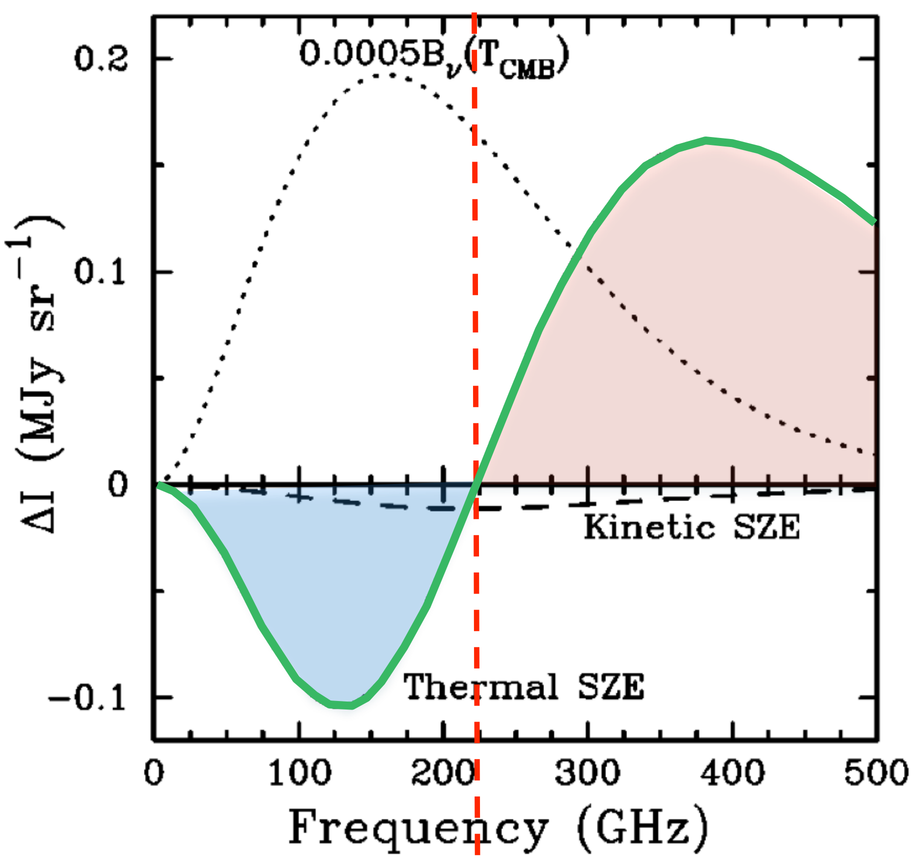
Universal shape

$$\Delta i_\nu = y \cdot j_\nu$$

$$y \propto \int_{los} n_e \cdot T_e \cdot dl$$

negative

positive




Zero-crossing ~ 220 GHz

# Observed signal

- Cluster brightness profile at observation frequency ν:

$$\Delta i_\nu(\mathbf{x}) = y(\mathbf{x}) \cdot j_\nu$$

Compton y parameter at position ***x***

SZ spectral function at frequency ν

$$y(\mathbf{x}) = y_0 \cdot T_{\theta_c}(\mathbf{x})$$

Integral of $p_e$
$p_e$ ~ NFW profile

Normalized cluster profile

- Observed maps contain noise + cluster at $x_0$

$$M_\nu(\mathbf{x}) = y_0 \cdot j_\nu \cdot T_{\theta_c}(\mathbf{x} - \mathbf{x}_0) + N_\nu(\mathbf{x})$$

$$\mathbf{M}(\mathbf{x}) = y_0 \cdot \mathbf{j}_\nu \cdot T_{\theta_c}(\mathbf{x} - \mathbf{x}_0) + \mathbf{N}(\mathbf{x})$$

known signal (if size known)

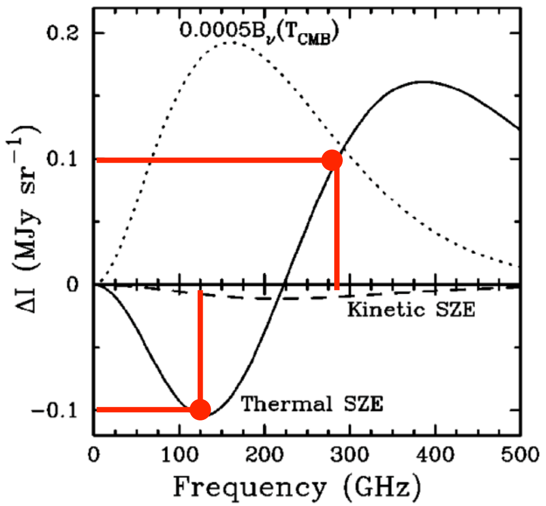
noise

# Toy example

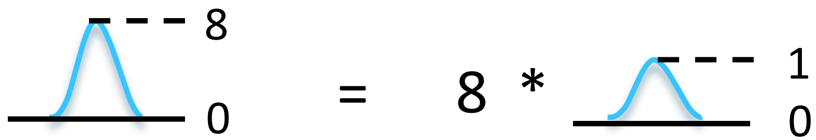
- 2 frequencies

$$j_{\nu 1} = +0.1$$

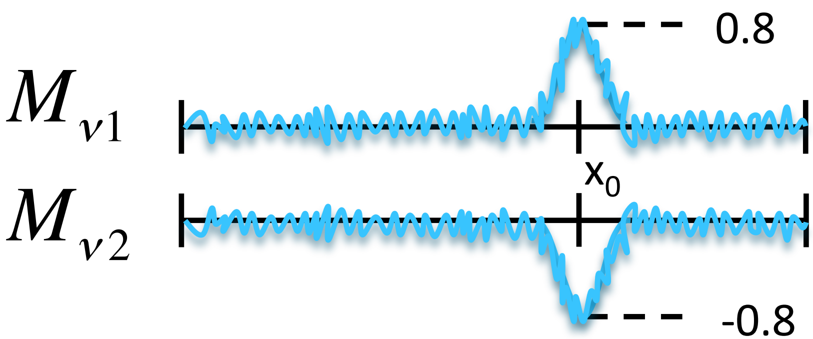
$$j_{\nu 2} = -0.1$$




- Integration of $p_e$:




- Observed maps:



# Matched filter

- The minimum variance unbiased estimator of the profile amplitude $y_0$ is:

$$\hat{y}_0(\mathbf{x_0}) = \sum\sum \boldsymbol{\Psi}^t_{\theta_c}(\mathbf{x}-\mathbf{x_0})\cdot \mathbf{M}(\mathbf{x})\cdot \mathbf{dx}$$

where:

$$\boldsymbol{\Psi}_{\theta_c}(\mathbf{k}) = \frac{\mathbf{P}^{-1}(\mathbf{k})\cdot \mathbf{j}_\nu \cdot T_{\theta_c}(\mathbf{k})}{\sum\sum \left[\mathbf{j}_\nu \cdot T_{\theta_c}(\mathbf{k})\right]^t \cdot \mathbf{P}^{-1}(\mathbf{k})\cdot \mathbf{j}_\nu \cdot T_{\theta_c}(\mathbf{k})\cdot \mathbf{dk}}$$

P(k) = Noise power spectrum

Known signal

# Toy example

- Suppose uncorrelated IID Gaussian noise

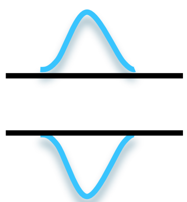
Known signal

$$\sim \mathcal{N}(0,\sigma^2) \quad \Rightarrow \quad \mathbf{P}(\mathbf{k}) = \sigma^2 \cdot \mathbf{I} \quad \Rightarrow \quad \boldsymbol{\Psi}_{\theta_c}(\mathbf{k}) \propto \mathbf{j}_\nu \cdot T_{\theta_c}(\mathbf{k})$$

- Filter:

$\boldsymbol{\Psi}_{\nu 1}$

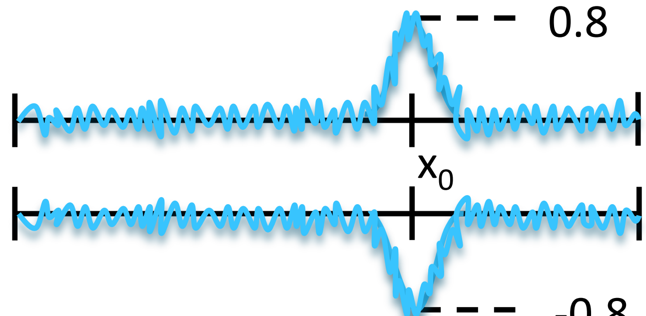
$\boldsymbol{\Psi}_{\nu 2}$



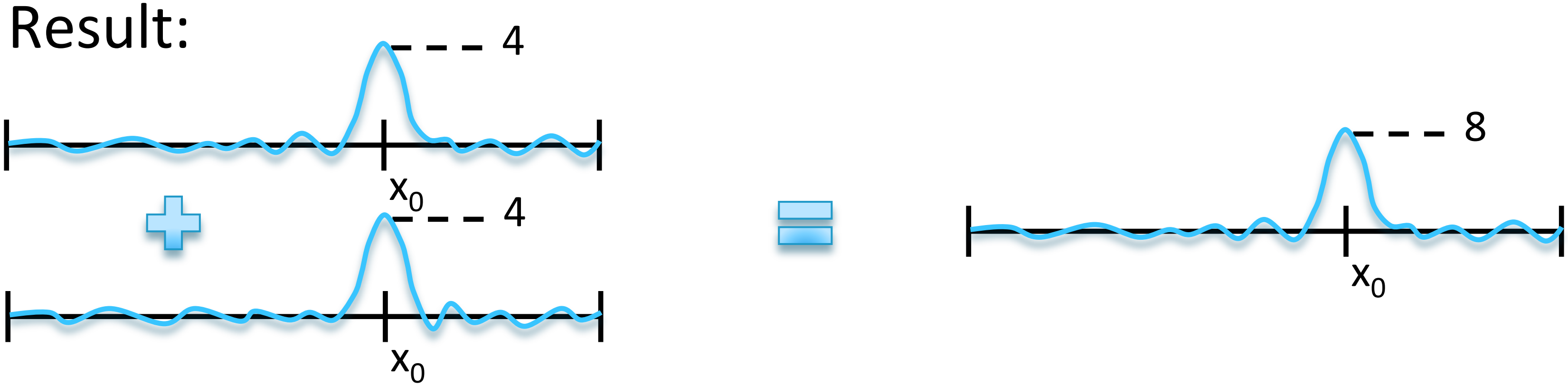
- Signal:

$M_{\nu 1}$

$M_{\nu 2}$

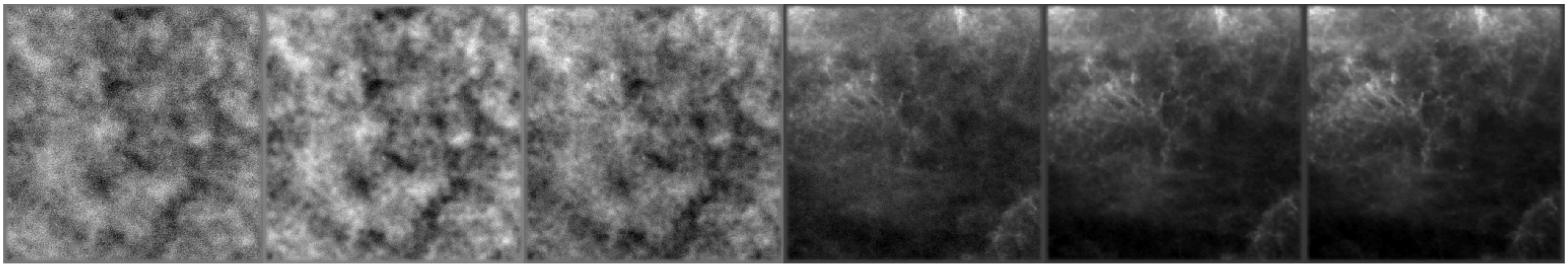



- Result:

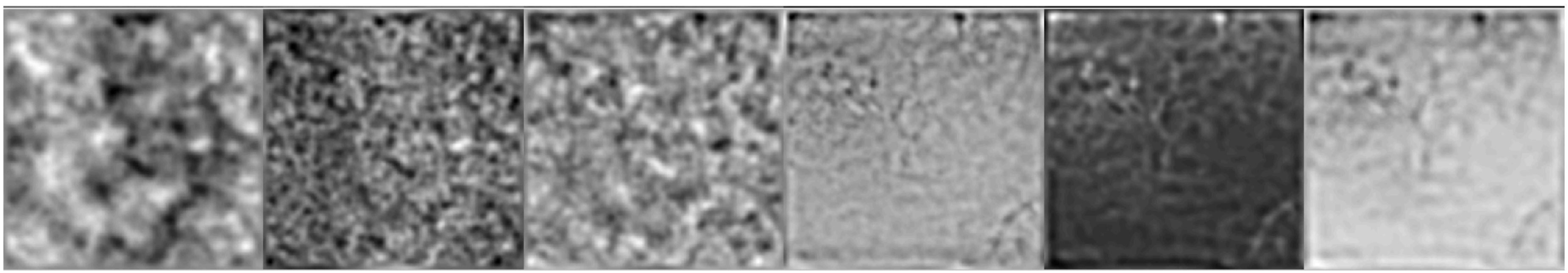


# Example

Observed maps at each frequency

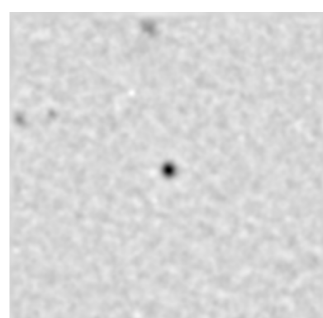


Filtered maps at each frequency



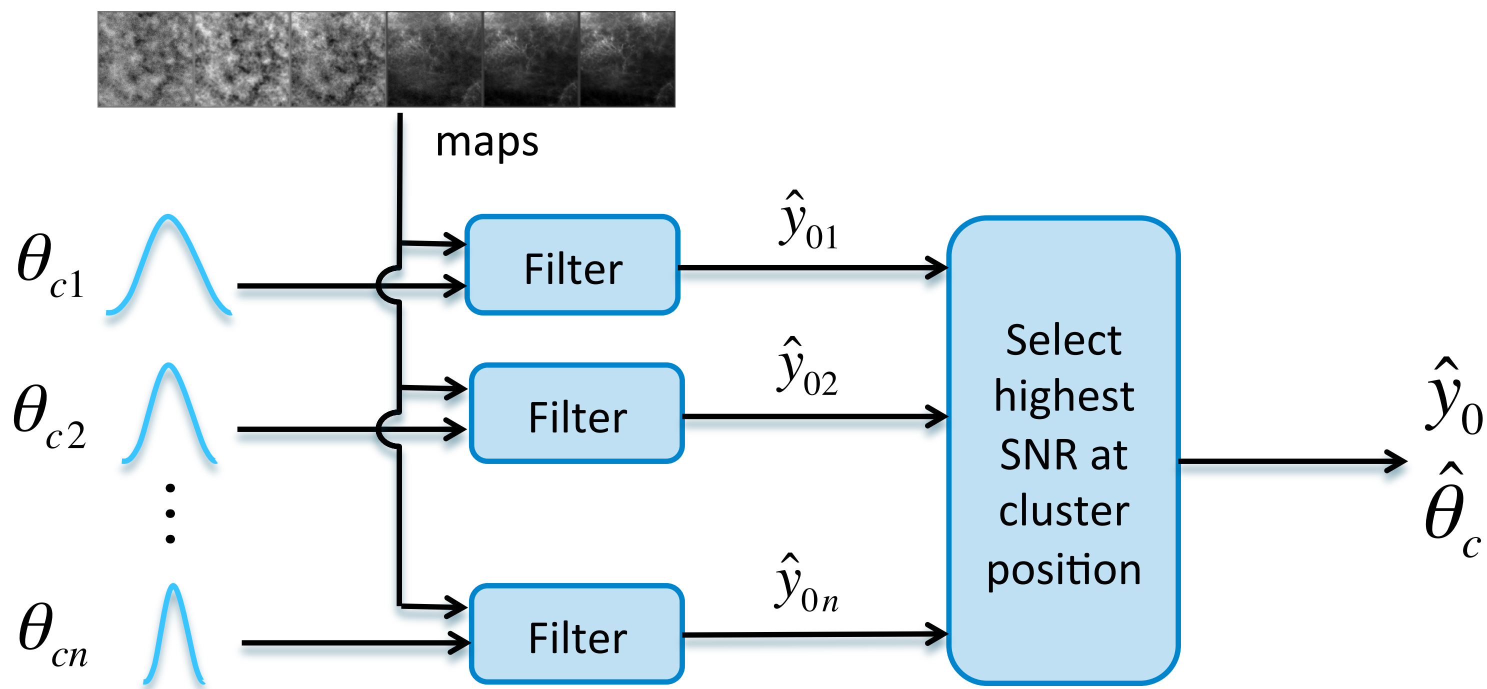
ν=100GHz ν=143GHz ν=217GHz ν=353GHz ν=545GHz ν=857GHz

Filtered map



# Unknown cluster size

- Create normalized cluster profiles $T_{\theta ci}$ for various cluster sizes
- Filter image for each cluster size
- Select result with higher SNR



# The X-ray map

- Emission measure is proportional to $n_e^2$

Integral of $n_e^2$
$n_e^2$ ~ NFW profile

- Cluster brightness profile:

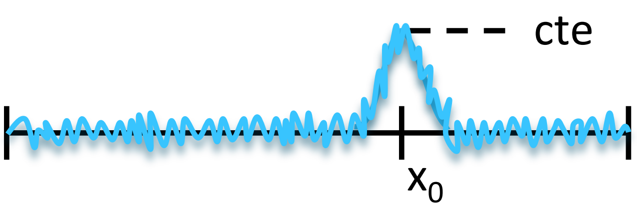
$$m(\mathbf{x}) = cte \cdot T_{\theta_c}(\mathbf{x})$$

- Observed maps contain noise + cluster at $x_0$

$$M(\mathbf{x}) = cte \cdot T_{\theta_c}(\mathbf{x} - \mathbf{x}_0) + N(\mathbf{x})$$

known signal (if size known)

noise



# MMF for X-ray map

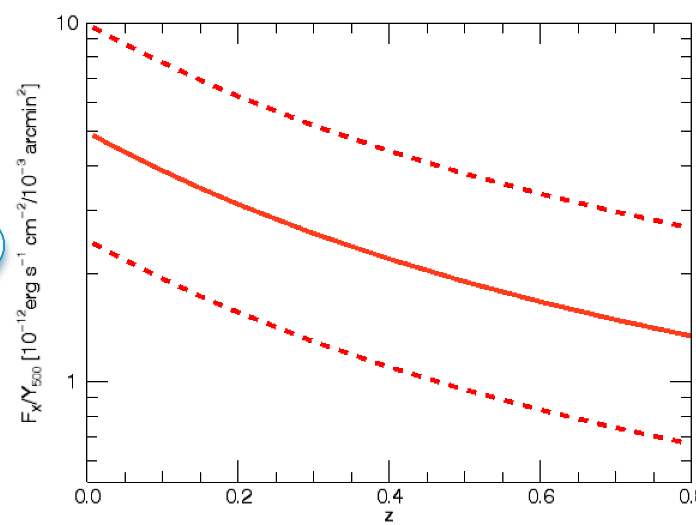
- The X-ray detection problem is equivalent to the SZ detection problem (known signal with unknown amplitude under noise)
- We can apply the same filter
- But we need to take into account the differences
  - The cluster profile is different
  - We have Poisson noise

# Combined MMF

- The SZ MMF takes as input 6 frequency maps
- We add the X-ray map as a 7$^{th}$ frequency map
- To do this we need to express the two maps in the same units

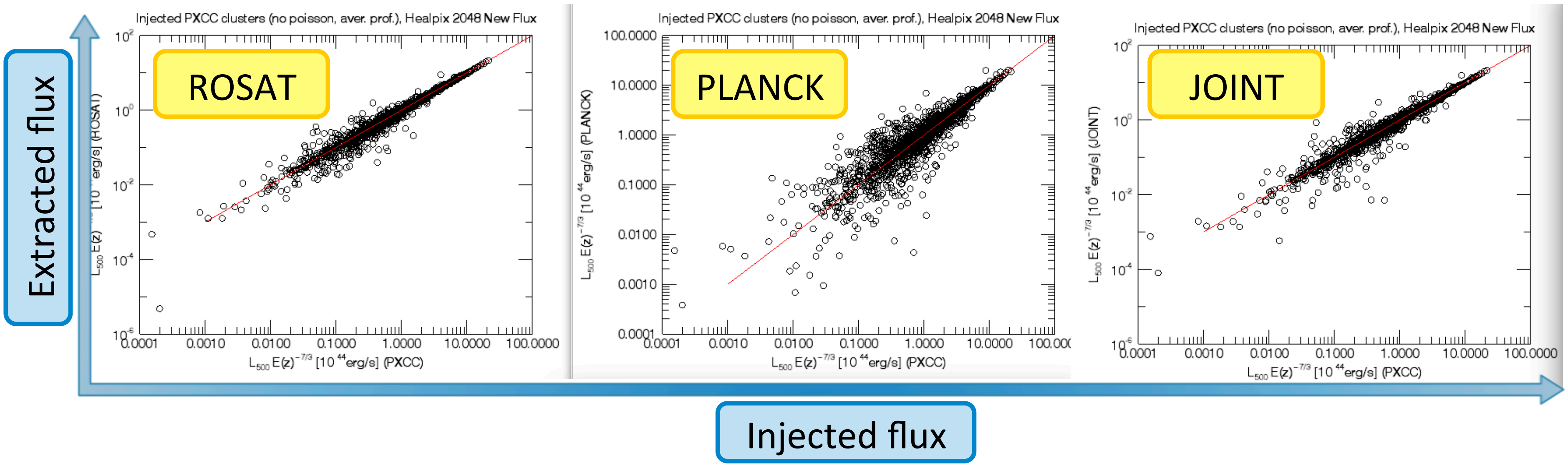
X-ray flux [erg/s/cm$^2$] → $Y_{500}$ [arcmin$^2$]

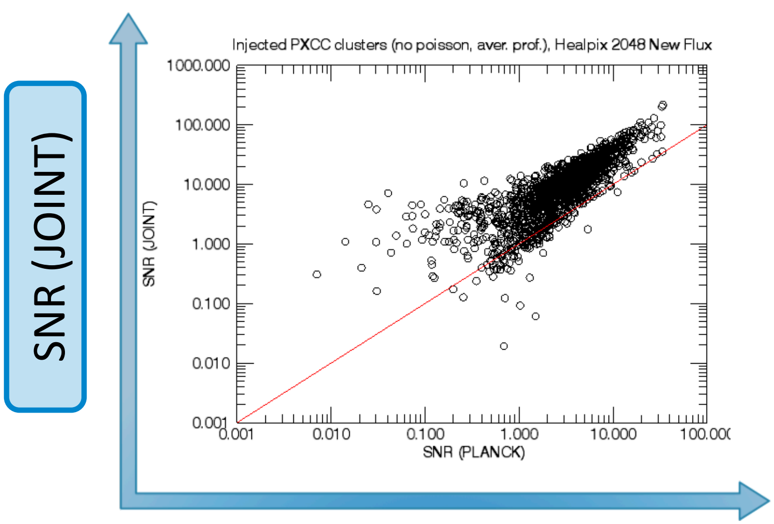
$$\frac{F_X[erg \cdot s^{-1} \cdot cm^{-2}]}{Y_{500}[arcmin^2]} = 4.95 \cdot 10^{-9} \cdot E(z)^{5/3} \cdot (1+z)^{-4} \cdot K(z)$$




* Planck intermediate results I, 2012

# Ideal simulation of PXCC clusters




Ideal PXCC clusters injected
- using average profile
- no Poisson fluctuations

# Questions?