Detection of hot gas in multi-wavelength datasets

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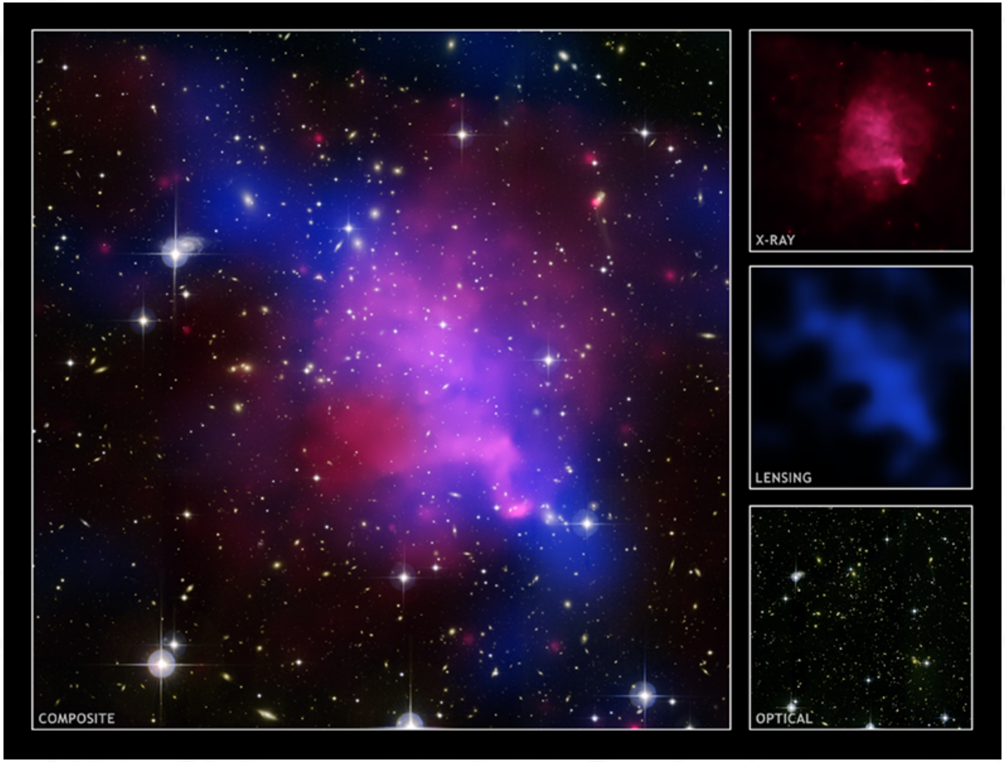
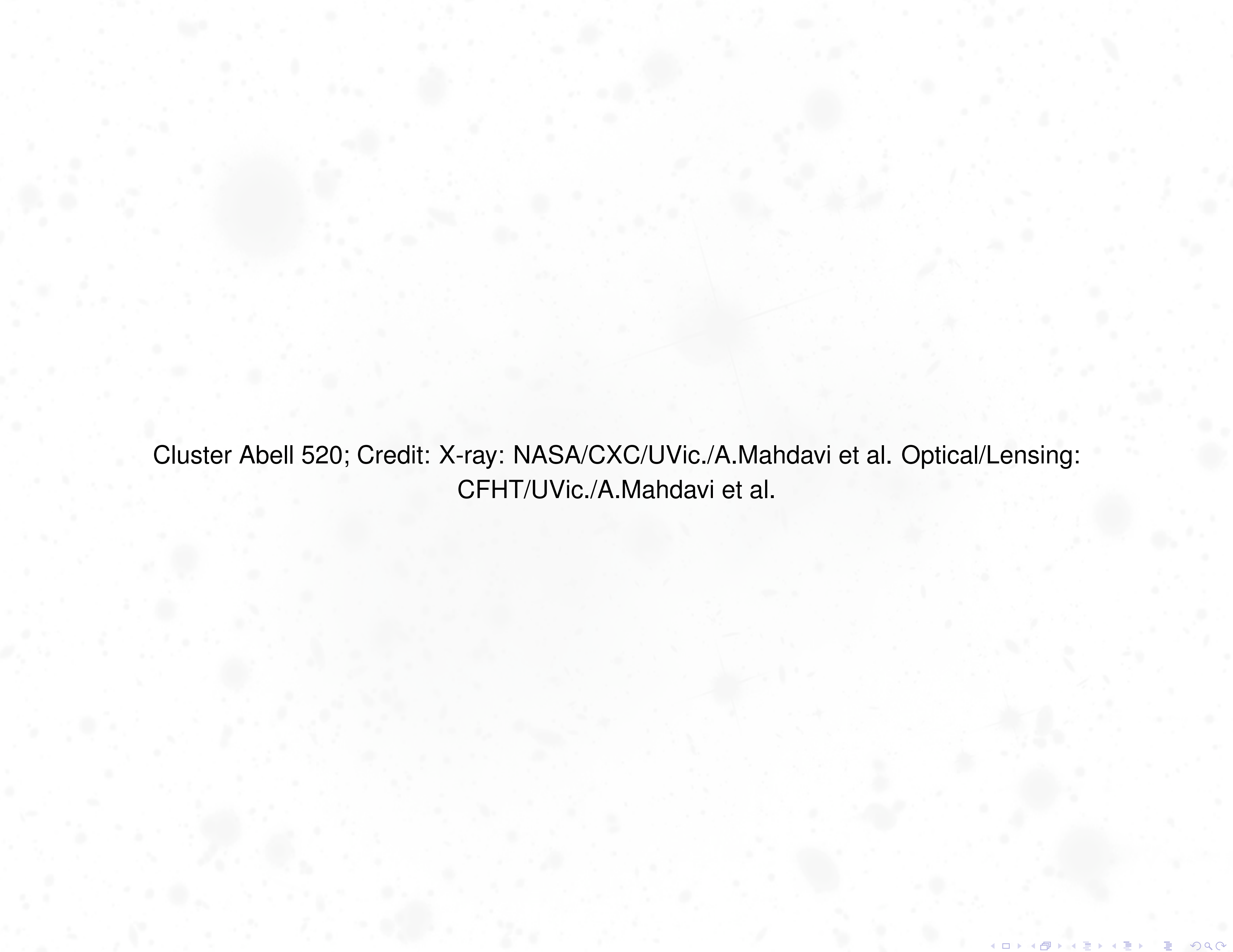
SPP

DDAYS 2015





Cluster Abell 520; Credit: X-ray: NASA/CXC/UVic./A.Mahdavi et al. Optical/Lensing: CFHT/UVic./A.Mahdavi et al.

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A short self-introduction

My work

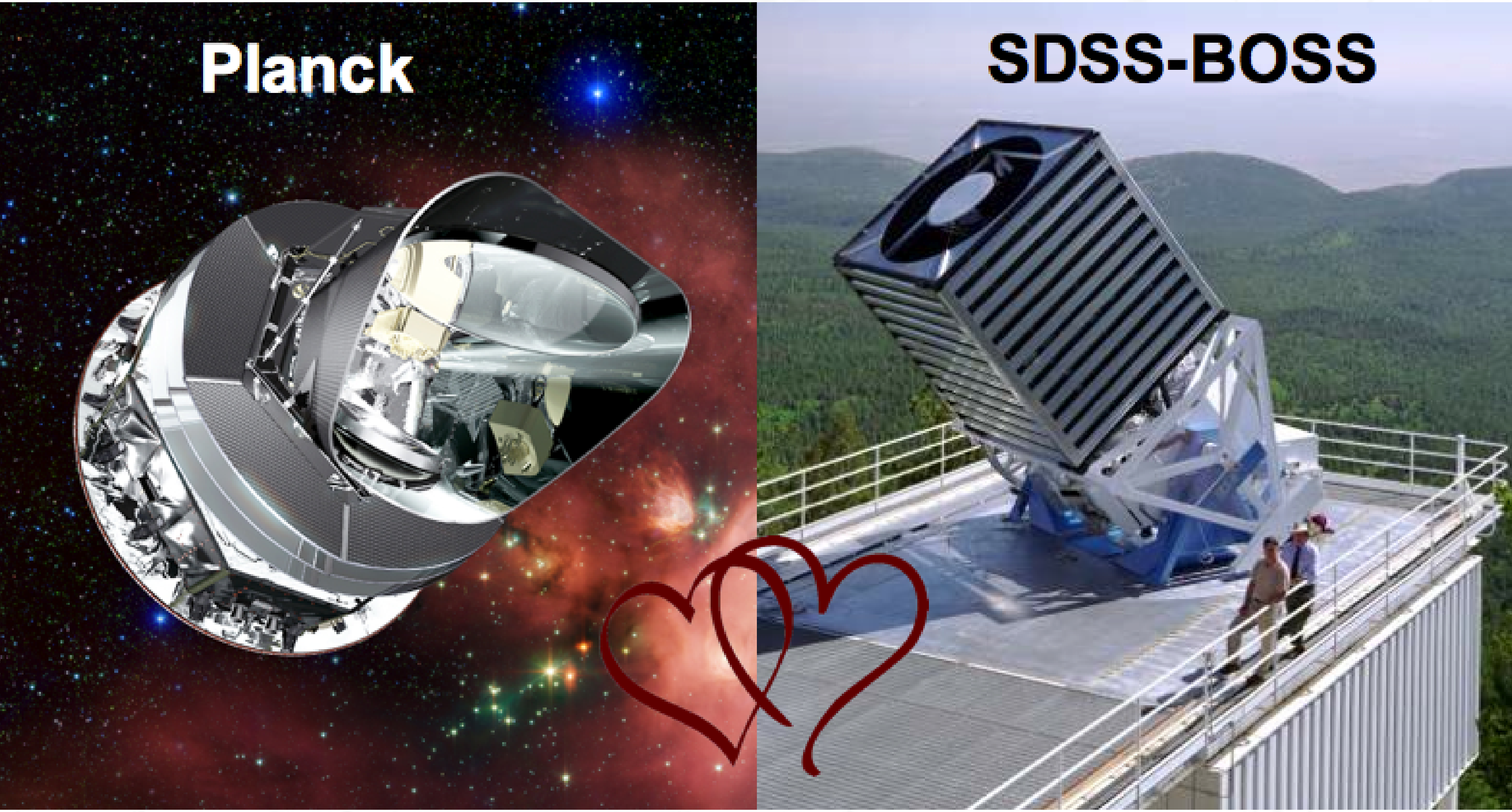
- PhD student at Service de Physique des Particules.
- Working on galaxy cluster detection using hot gas emissions.
- Supervisor: Jean-Baptiste Melin

Before my PhD

- Master degrees in Astrophysics at Grenoble INP Engineering school/ Université Joseph Fourier at Grenoble.
- Master thesis: "Galaxy survey seen by the Minkowski Functionals" under the direction of Carlo Schimd (Laboratoire d'Astrophysique de Marseille)

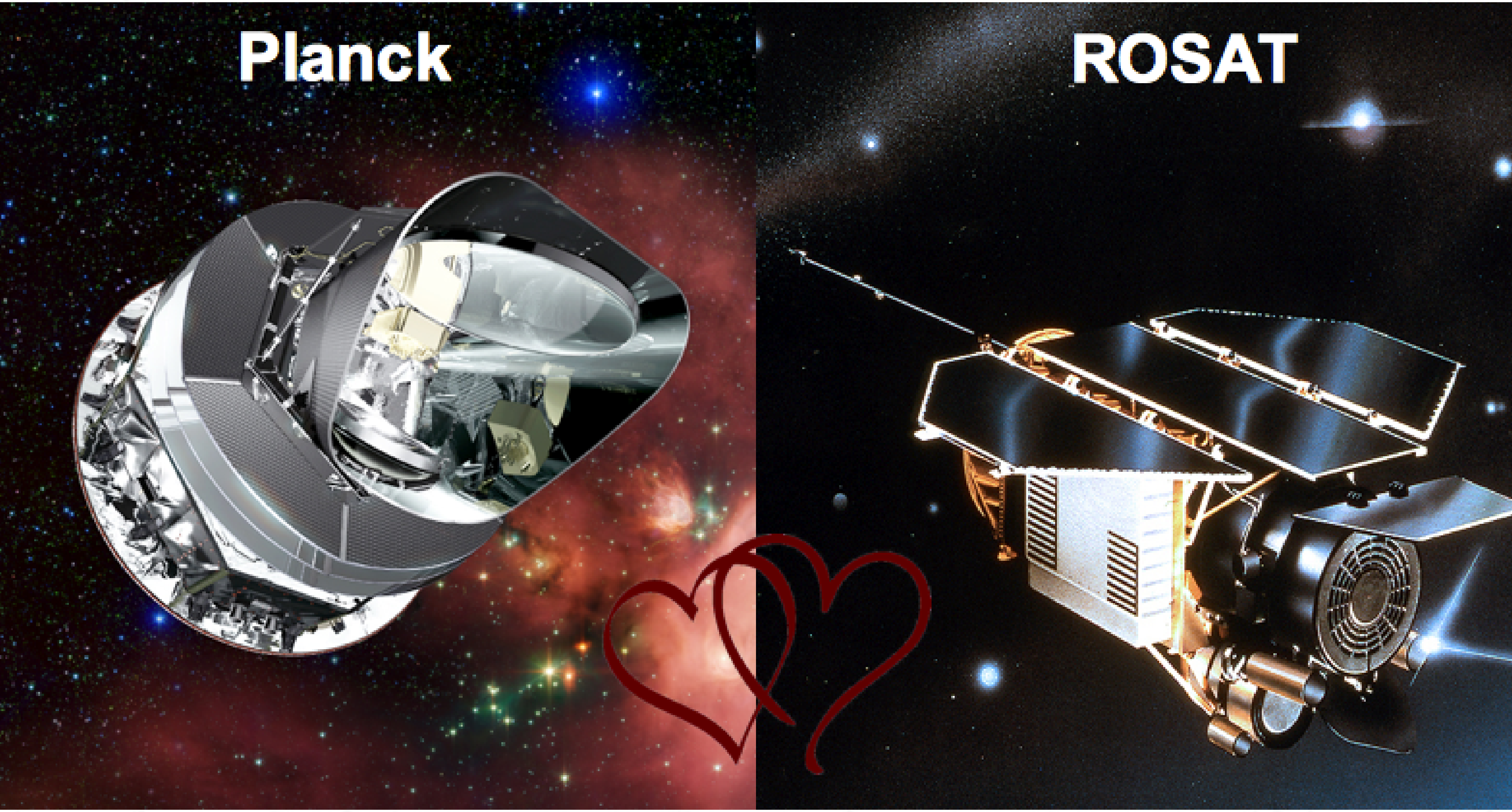
Collaborations

- Hot gas in distant structure: Christophe Yèche and the BOSS group at SPP and Jim Bartlett at APC.
- Simultaneous detection of low-z cluster: Monique Arnaud and the cluster group at SAp.



The first wedding

- Planck: SZ effect (detection of clusters in millimeter data), catalogue of galaxy clusters.
- BOSS: BAO, Lα and a catalogue of QSO.
- Combination SZ effect and QSO: QSO as tracers of distant clusters of galaxies?



The second wedding

- Planck: SZ effect, catalogue of galaxy clusters.
- ROSAT (late 1990's X-ray satellite): Bremsstrahlung, catalogue of galaxies clusters.
- Combination of SZ and X-ray : a deeper catalogue expected.

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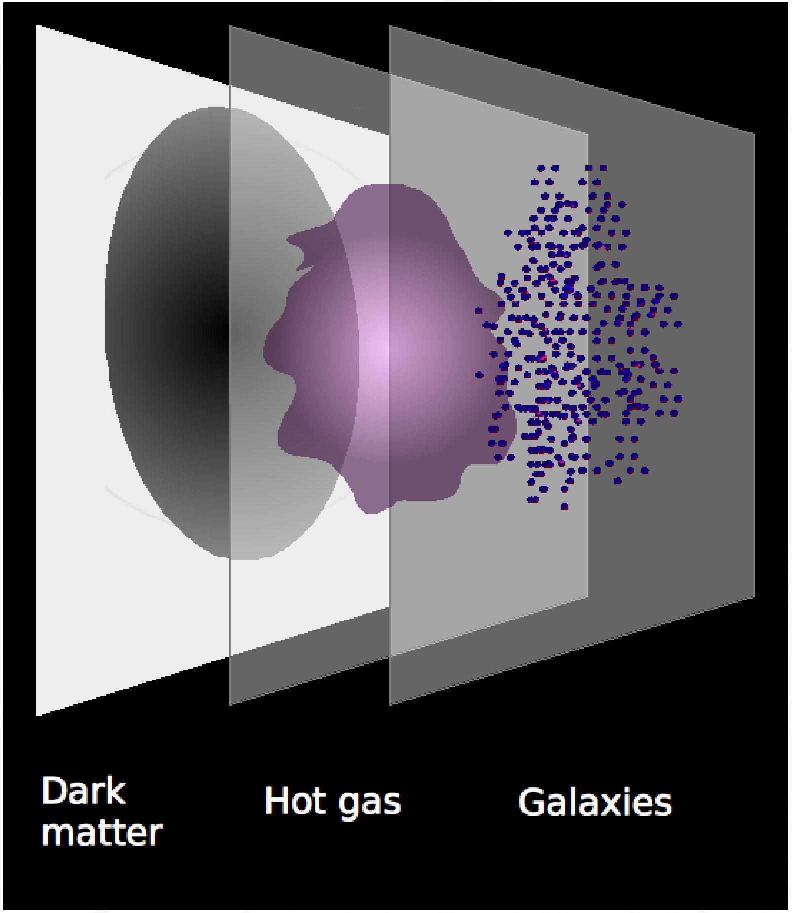
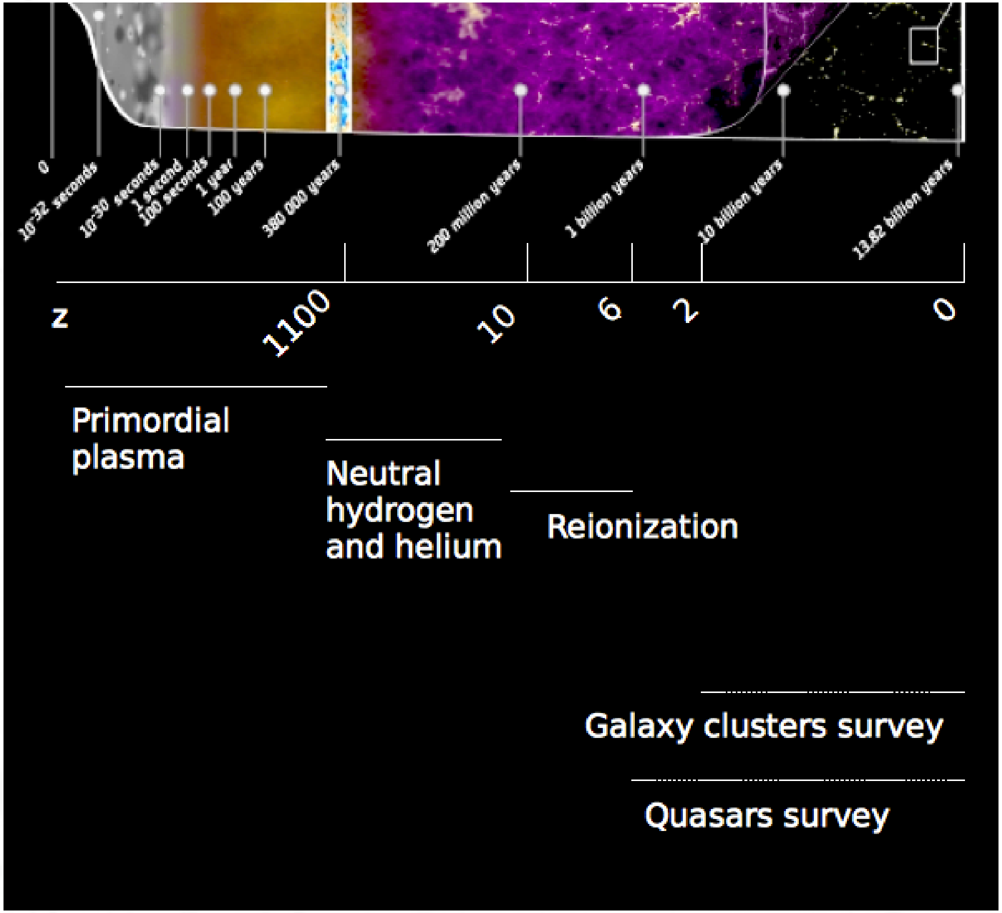
What is a galaxy cluster?



Main features

- Composition: $\sim 85\%$ dark matter, $\sim 15\%$ baryonic matter ($\sim 3\%$ galactic gas, $\sim 12\%$ intergalactic hot gas)
- Origin: the primordial over-densities of matter
- Formation by gravitational collapse

What is a galaxy cluster?

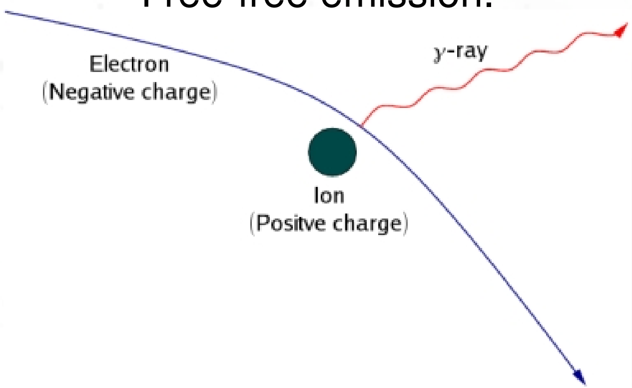


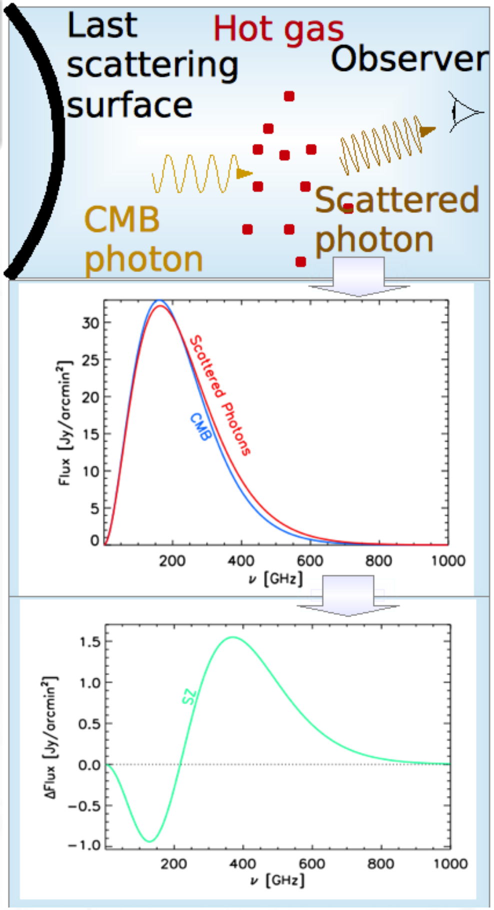
Story of the universe at different redshift; hot gas reappears during the reionization era.

The x-ray Channel

- Mainly Bremsstrahlung : free-free electron/ion process.

Free-free emission.





Sunyaev-Zel'dovich effect

- **Inverse Compton scattering** of the CMB photons.
- Amplitude : $Y_{500} = f(M_{gas})$.

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Individual detection at low redshift

Individual detection of clusters is possible for low-redshift structures. Some actual limits:

- millimeter wavelength: SPT survey: detection of clusters up to z=1.5
- X-ray: Chandra confirmed a cluster at z=2.07.

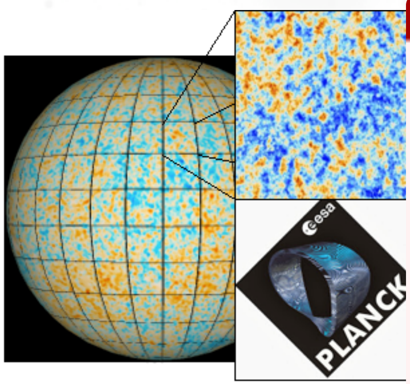
A statistical approach at high redshift

- Individual detection not possible (fainter objects) : **statistical approach** is required.
- Via the **Sunyaev-Zel'dovich effect**. We use the Planck maps at seven frequencies (70, 100, 143, 217, 353, 545 and 857 GHz).
- Need an **independent tracer** for the hot gas : quasars from SDSS survey (redshift range from 0.1 to 6.44). Optical detection.
- Quasars: very bright object hosted by galaxies, expected to be created and to live in relatively dense environment on average.
- Look at the positions of them on the Planck maps and extract a flux.
- To increase the signal-to-noise, we work with the **average flux**.

Detection of hot gas in distant structures (Planck+BOSS)

Find a signal (1)

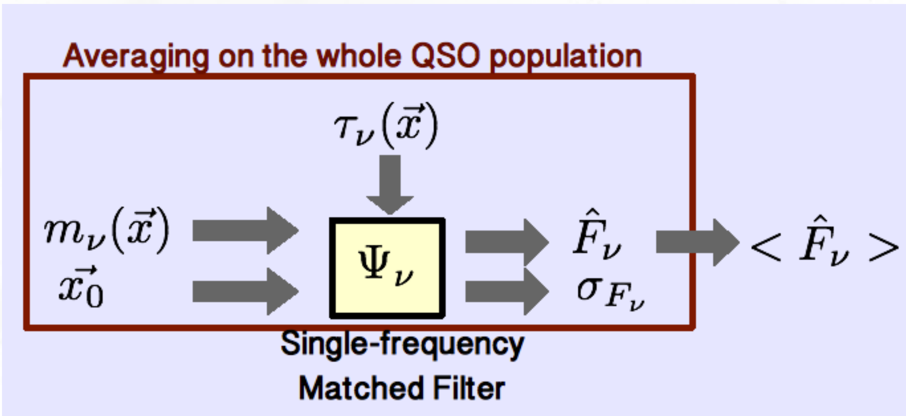
First step: what is the nature of the signal at the QSO's positions?



Formal description of a Planck map

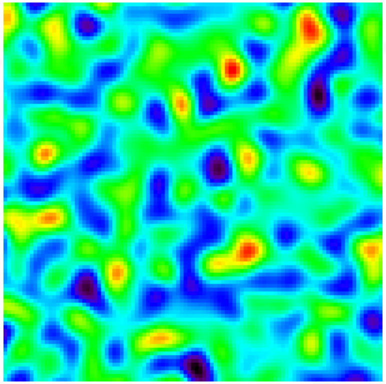
$m_\nu(\vec{x}) = F_\nu \cdot \tau_\nu(\vec{x} - \vec{x_0}) + n_\nu(\vec{x})$ with

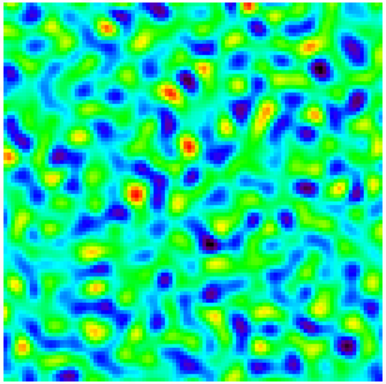
- $m_\nu(\vec{x})$, the Planck map at $\vec{x} = (RA, DEC)$,
- F_ν, the flux from the structure (quasar and hot gas),
- $\vec{x_0}$ the quasar's position,
- $\tau_\nu(\vec{x})$ the spatial profile (GNFW) of the cluster (convolved with the Planck beam) and
- $n_\nu(\vec{x})$ the instrumental and astrophysical noise .

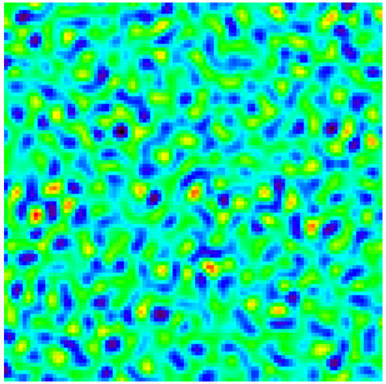


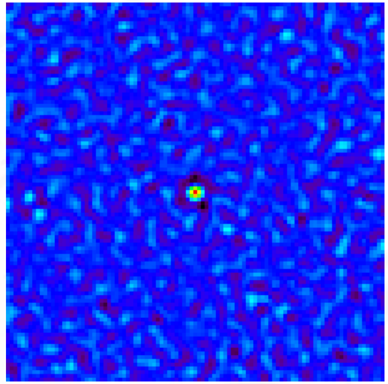
Average flux

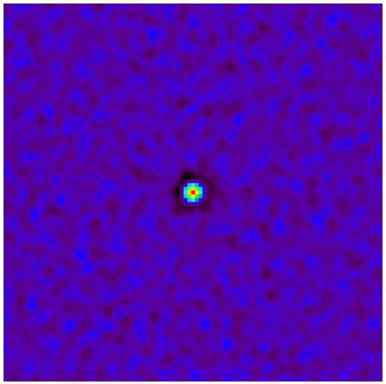
Average filtered maps centered on the quasar's positions.

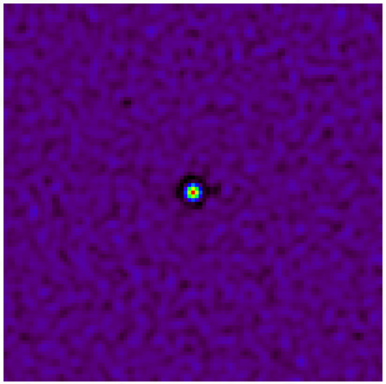

Average filtered map at 70 GHz

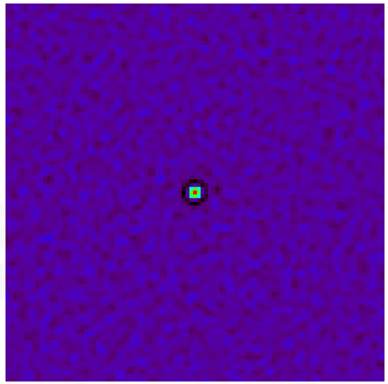

Average filtered map at 100 GHz


Average filtered map at 143 GHz

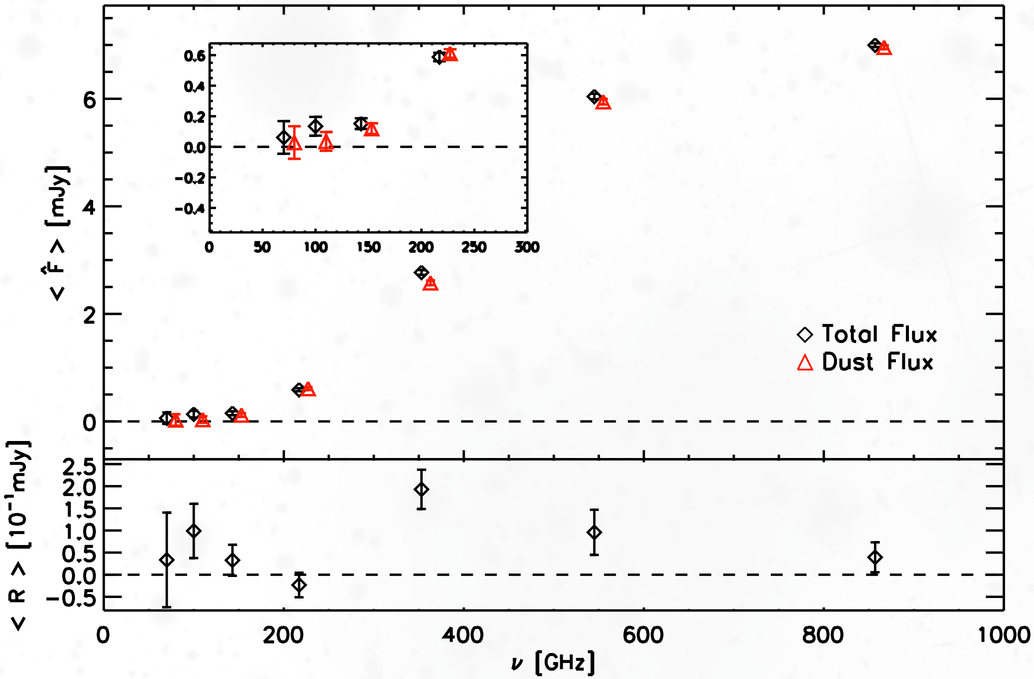

Average filtered map at 217 GHz

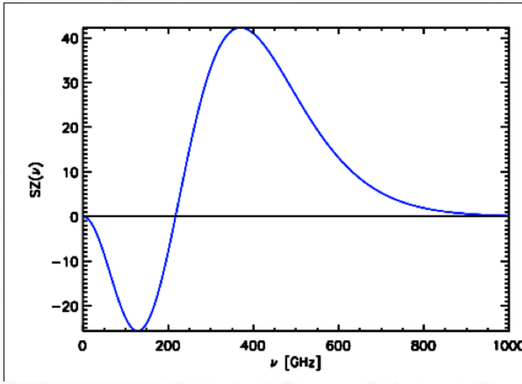

Average filtered map at 353 GHz


Average filtered map at 545 GHz

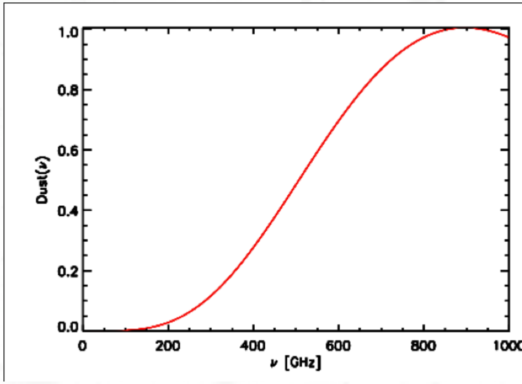

Average filtered map at 857 GHz

Detection of hot gas in distant structures (Planck+BOSS)





SZ spectrum



Dust modeled as a grey body

Dust emission dominates

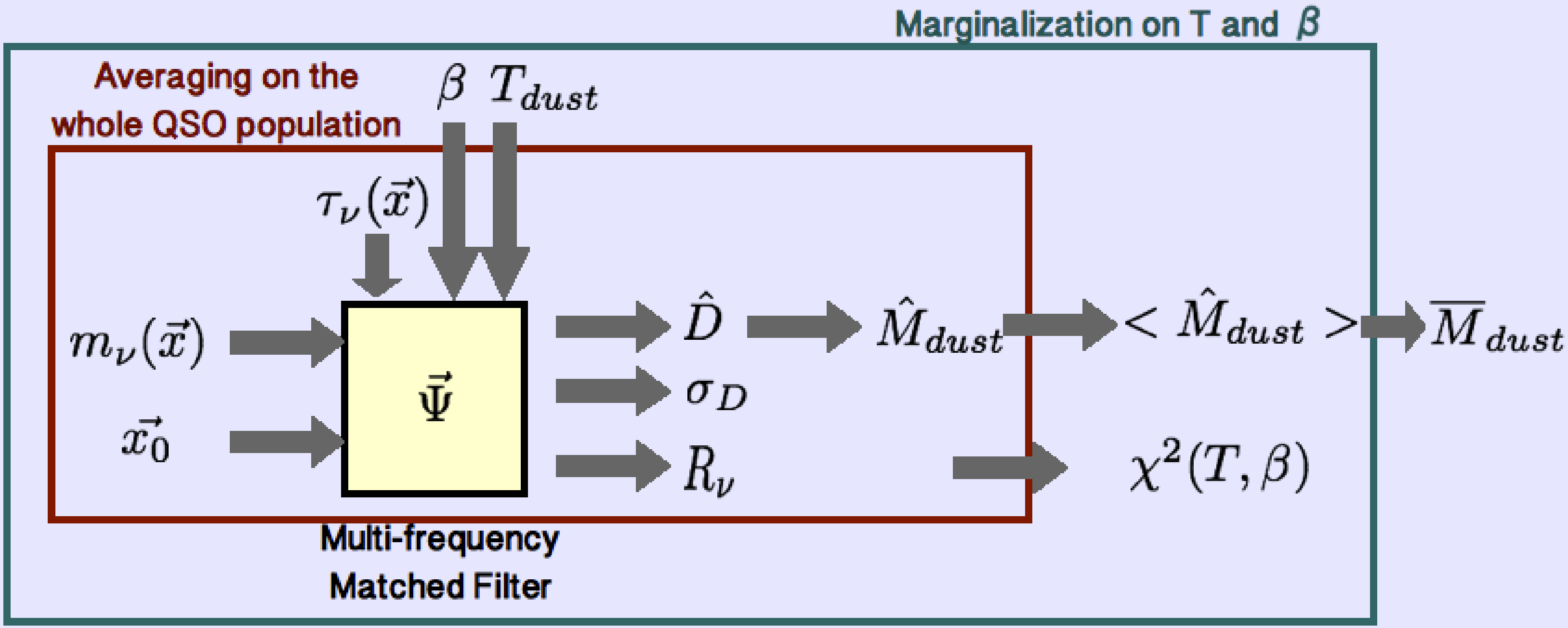
- Average flux : a grey body rather than a SZ spectrum.
- Emissions from grains of dust heated by stars.

Find a signal (2)

Second step: extract the dominant component of the signal, the dust emission.

Deal with the dust

- Assume $F_\nu = D \cdot dust(T_{dust}, \beta, \nu)$ (dust only)



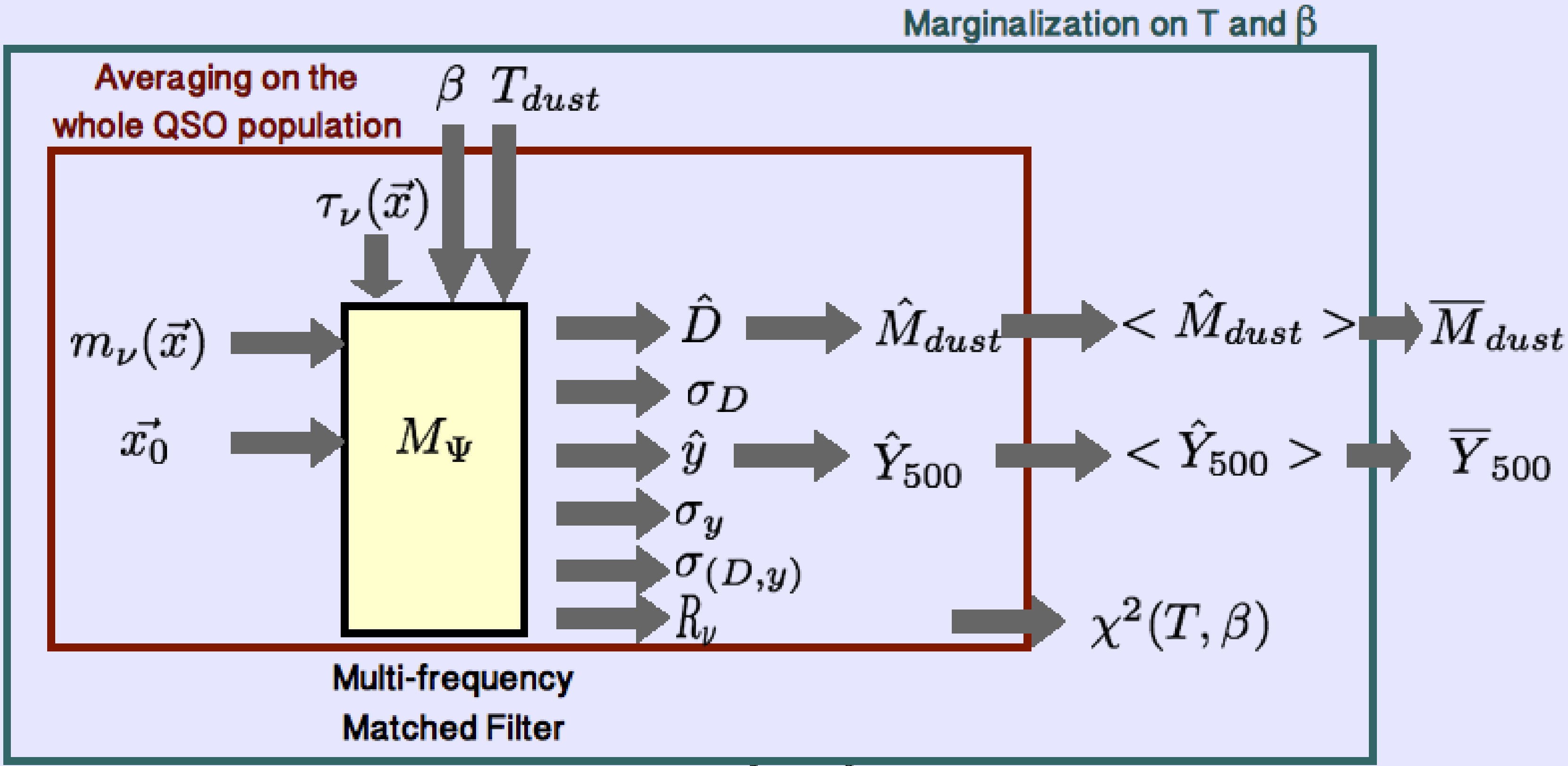
$$R_\nu = \hat{F}_\nu - \hat{D} \cdot dust(T, \beta, \nu)$$

Find a signal (3)

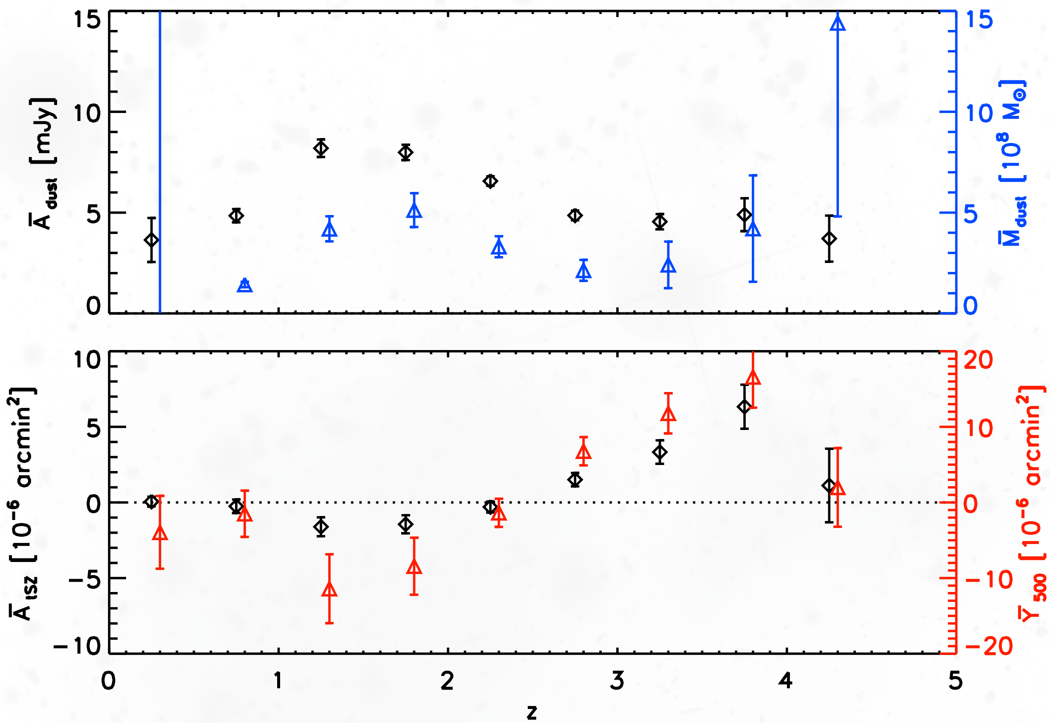
Third step: extract the sub-dominant SZ signal.

Deal with the dust and the SZ

- Assume $F_\nu = D \cdot dust(T_{dust}, \beta, \nu) + y \cdot SZ(\nu)$



$$R_\nu = \hat{F}_\nu - \hat{D} \cdot dust(T, \beta, \nu) - \hat{y} \cdot SZ(\nu)$$



Interesting sub-population of QSO

- Most promising sample for the SZ signal is the bin $z \in [2.5, 4.]$ of quasars without radio counterpart (from FIRST).
- Significant signal from the hot gas. Cluster mass estimated at $1.72 \pm 0.13 h^{-1} 10^{13} M_\odot$. Coherent with the QSO clustering analysis $1.41 \pm 0.6 h^{-1} 10^{13} M_\odot$ (Richardson et al 2012).

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Clusters catalogue

- Goal: construct a new catalogue of clusters to constrain the cosmological parameters or to study cluster physics.

A new filter

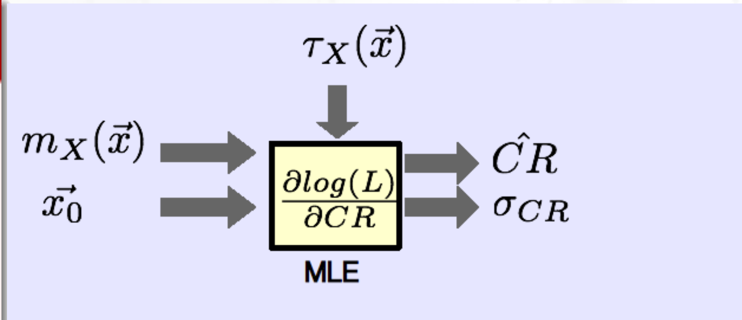
- Develop a new filter combing the data from the **Planck maps** at different frequencies with the data from **X-ray maps** (ROSAT).
- The problem of the noise. Planck maps have **Gauss-distributed** noise whereas ROSAT maps follow a **Poisson distribution**.
- First step: develop a filter adapted for a poisson distribution for the ROSAT map (work in progress)
- Second step: combine this filter with a matched-filter dealing with the Planck data.
- Third step: Find new clusters

The X-ray filter

- **Maximum-Likelihood Estimation (MLE)**
- Test the filter on already-known sources. MCXC catalogue (catalogue of X-ray clusters) : 1789 clusters with a known redshift and a known mass. We have a catalogue of count rate a
- We build 1789 ROSAT patches centered on the MCXC clusters
- For each patch: 350 pixels per 350 pixels (10 degrees per 10 degrees)
- For each pixel i: a count (an integer) s_i and an exposure time t_i for the exposure maps.

A simple model with a cluster and a constant rate background

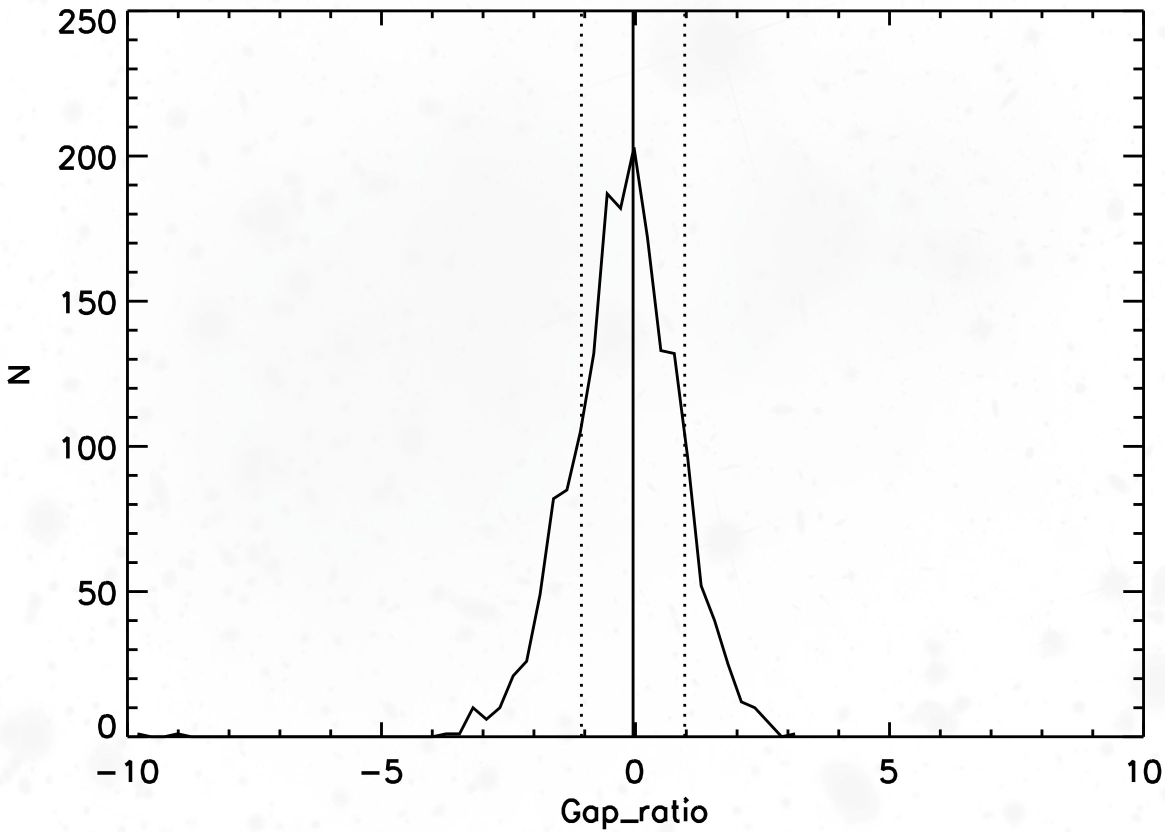
- We assume the probability to have s_i to be Poisson with a mean m_i; we assume a **model** $m_i = a \times \tau_i + b \times t_i$.
- With b the background rate, a the cluster's count rate (CR) and $\tau_i = templates(\theta_s, x_i, y_i) \times t_i$. $templates$ is the normalized profile (Generalized NFW) of the cluster convolved with the ROSAT beam.



Simultaneous detection using X-ray/SZ data for lower-z clusters (Planck+ROSAT)

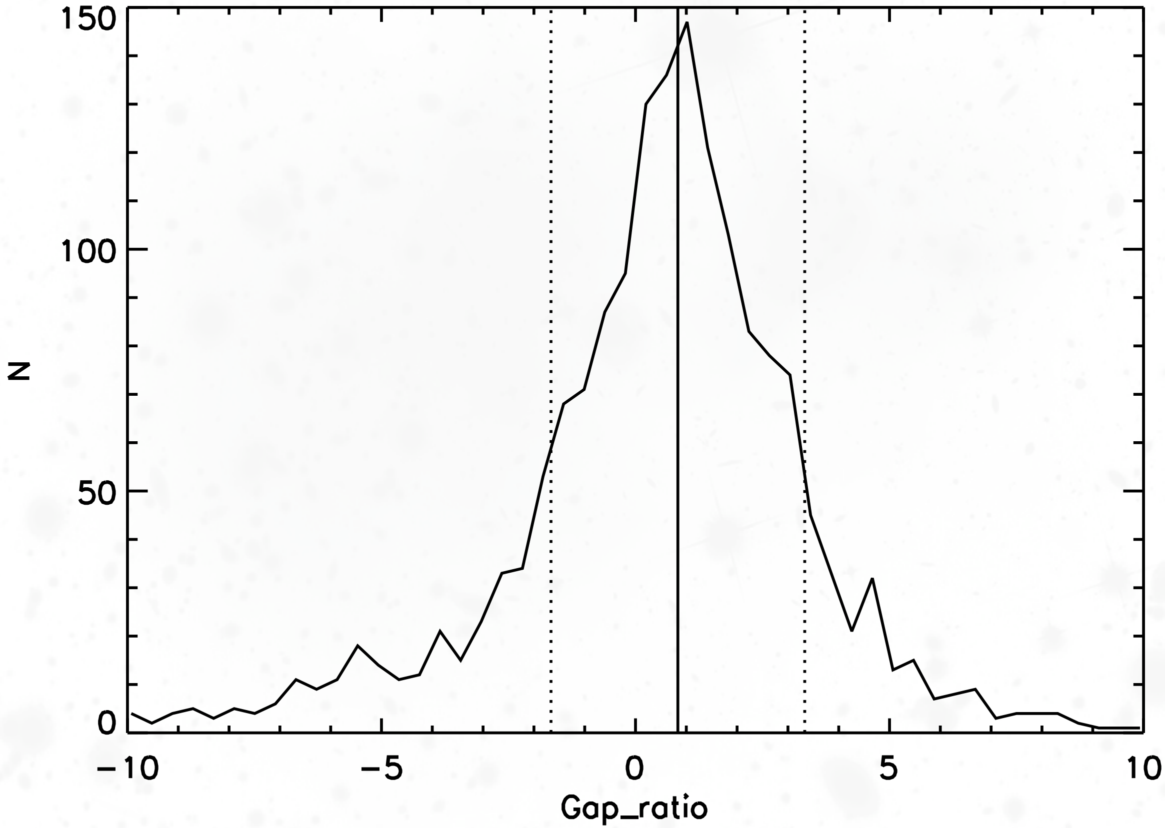
Results on simulated clusters

- Gap ratio= $\frac{\hat{a}-a_{input}}{\sigma_a}$
- No bias and over-dispersion.



Results on the MCXC clusters

- Gap ratio= $\frac{\hat{a}-a_{input}}{\sigma_a}$
- Large dispersion. Need to improve the model used in the likelihood.



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Conclusion

Evidence for hot gas in high redshift structures (Planck+BOSS)

- A much more complicated analysis than expected due to a strong presence of dust and synchrotron.
- Strong evidence of **hot gas** (SZ signal) at the positions of radio-quiet quasars in the redshift range $[2.5, 4]$.
- Origin of this SZ signal difficult to determine: galaxy clusters, galaxy groups or haloes of gas around the QSO?

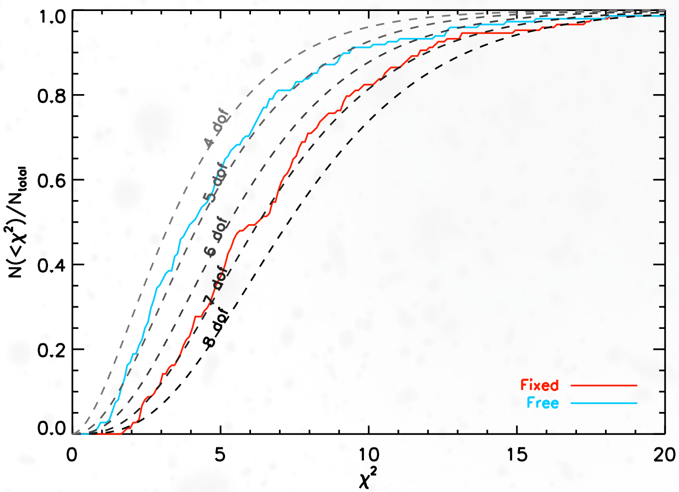
Simultaneous filtering for lower-z cluster (Planck+ROSAT)

- Introduction of a "MLE" filter working on X-ray data.
- Large scatter in the estimated counts for the MCXC.
- Need for a more realistic model to be used in the likelihood.
- Work in progress . . .

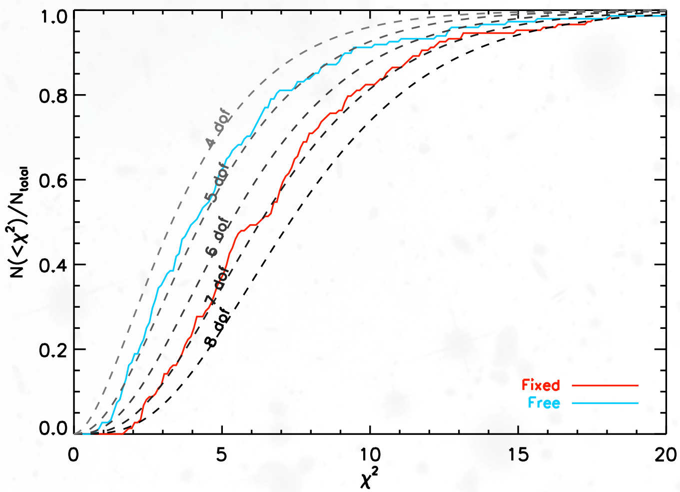
Thanks for your attention!

Samples and method

We build 148 sub-samples of 2000 quasars with random positions on the sky. At these positions, we inject a flux on the Planck maps to create the injected Planck map. In the first case, flux is a dust signal and we employ a dust filter. In the other case, it's a dust and SZ signal and we employ the dust + SZ filter. For each sub-sample, for both filters, we compute two χ^2: the first at the T_{dust} and β (fixed) of the injection and the second via a Powell algorithm (variable parameters). Both filters have the **same χ^2 distribution**.

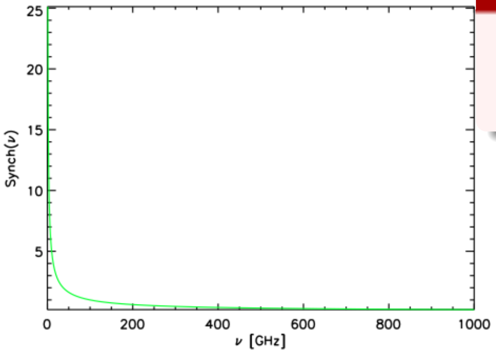


χ^2 distribution for dust filtering of dust emission



χ^2 distribution for dust + SZ filtering of dust + SZ emission

z_{min}	z_{max}	FIRST	Filter	$\chi^2/5$	T_d (K)	β_d	M_{dust} ($10^8 M_\odot$)	Y_{500} ($10^{-6}\,arcmin^2$)	M_{500} ($10^{13} M_\odot$)	L_{synch} ($10^{-3} L_\odot \mathrm{Hz}^{-1}$)
0.1	6.5	-	dust	16.3	28.1 ± 0.4	1.6 (fixed)	1.72 ± 0.07	-	-	-
0.1	6.5	-	dust	5.2	19.1 ± 0.8	2.71 ± 0.13	0.82 ± 0.07	-	-	-
0.1	6.5	-	dust+tSZ	9.1	18.6 ± 0.8	2.80 ± 0.13	0.74 ± 0.07	15.64 ± 0.76	3.18 ± 0.09	-
0.1	6.5	-	dust+synch	6.7	20.0 ± 1.0	2.52 ± 0.14	0.96 ± 0.09	-	-	0.33 ± 0.13
0.1	6.5	-	dust+tSZ+synch	16.1	21.3 ± 1.1	2.24 ± 0.15	1.22 ± 0.12	16.06 ± 0.78	3.22 ± 0.09	0.67 ± 0.13
2.5	4	-	dust	12.4	28.6 ± 0.3	1.6 (fixed)	7.99 ± 0.32	-	-	-
2.5	4	-	dust	4.2	21.9 ± 0.8	2.63 ± 0.14	2.78 ± 0.45	-	-	-
2.5	4	-	dust+tSZ	2.3	22.5 ± 0.9	2.59 ± 0.18	2.56 ± 0.52	7.98 ± 1.26	2.17 ± 0.20	-
2.5	4	-	dust+synch	3.8	23.8 ± 0.9	2.25 ± 0.16	4.39 ± 0.81	-	-	-26.03 ± 5.70
2.5	4	-	dust+tSZ+synch	3.4	23.5 ± 1.0	2.34 ± 0.22	3.76 ± 1.05	5.56 ± 2.12	1.57 ± 0.69	-11.41 ± 8.69
2.5	4	yes	dust	4.9	32.5 ± 5.1	1.24 ± 0.44	16.08 ± 6.31	-	-	-
2.5	4	yes	dust+tSZ	2.0	23.3 ± 3.2	2.01 ± 0.46	14.11 ± 6.15	-37.14 ± 7.00	-	-
2.5	4	yes	dust+synch	0.4	18.8 ± 2.8	3.72 ± 0.67	1.09 ± 1.12	-	-	233.48 ± 30.03
2.5	4	yes	dust+tSZ+synch	0.3	15.7 ± 3.3	5.33 ± 1.43	0.39 ± 0.68	14.86 ± 9.82	2.16 ± 1.81	279.60 ± 40.82
2.5	4	no	dust	4.4	21.8 ± 0.9	2.69 ± 0.19	2.54 ± 0.53	-	-	-
2.5	4	no	dust+tSZ	1.5	22.4 ± 1.2	2.68 ± 0.23	2.15 ± 0.55	10.02 ± 1.34	2.47 ± 0.19	-
2.5	4	no	dust+synch	2.7	24.0 ± 1.0	2.22 ± 0.18	4.41 ± 0.89	-	-	-33.68 ± 6.14
2.5	4	no	dust+tSZ+synch	2.3	23.6 ± 1.1	2.34 ± 0.23	3.66 ± 1.09	6.42 ± 2.26	1.77 ± 0.65	-16.92 ± 9.28



Synchrotron spectrum as a power-law

Interesting sub-population of QSO

- Quasars with radio counterpart strongly contaminate the signal with a synchrotron (power-law) emission.