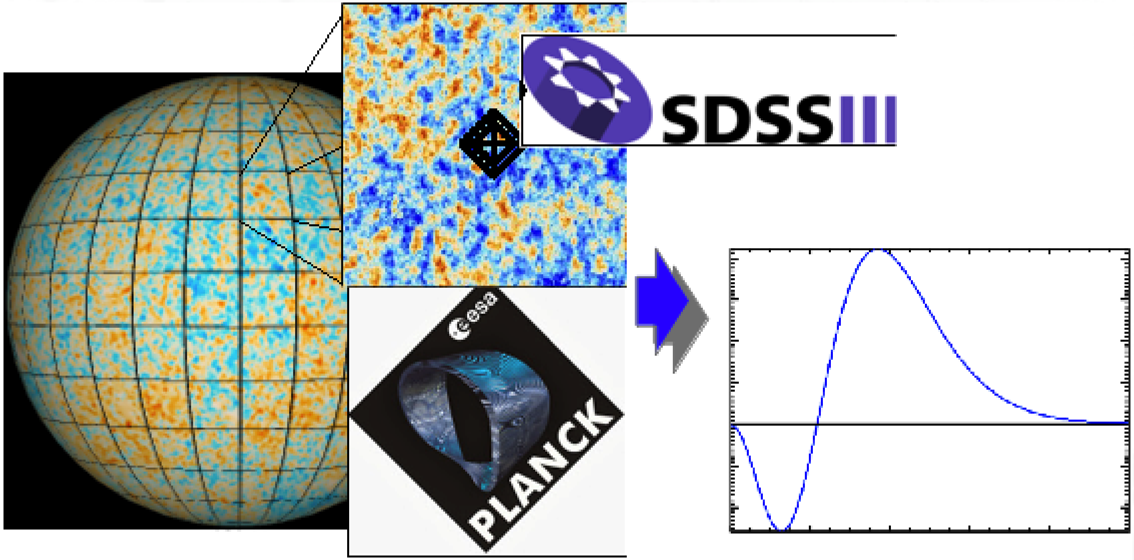
Thermal Sunyaev-Zel'dovich effect from high redshift (z > 2) structures

Loïc Verdier

CEA Saclay

March 2016

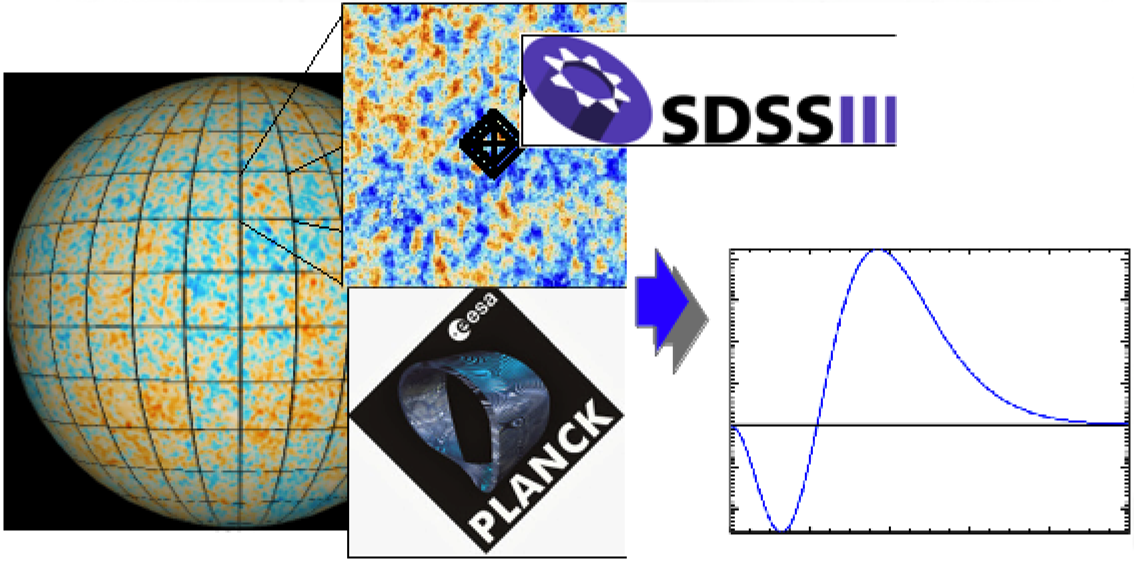


Thermal Sunyaev-Zel'dovich effect from high redshift (z > 2) structures

Loïc Verdier

CEA Saclay

March 2016



Based on : *Loïc Verdier, Jean-Baptiste Melin, James G. Bartlett, Christophe Magneville, Nathalie Palanque-Delabrouille and Christophe Yèche, 2016, A&A, 588, A61*

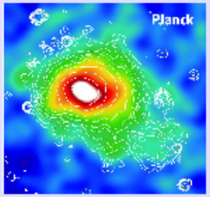
DE LA RECHERCHE À L'INDUSTRIE
cea

Table of contents

Hot gas structures

z>3 | 3>z>2 | 2>z>1 | 1>z>0

Coma cluster

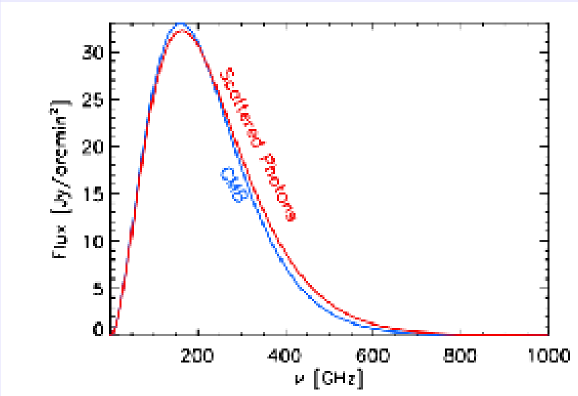


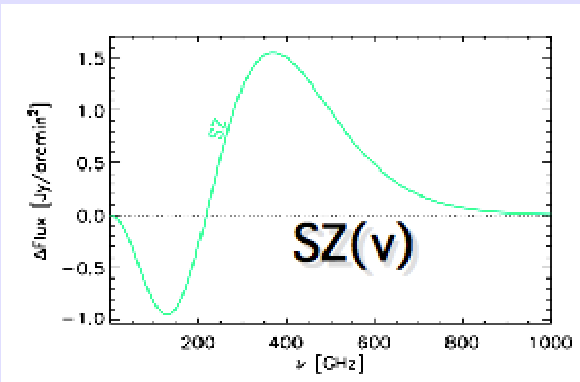
z=0.02

Detection of galaxy clusters/hot gas structures?

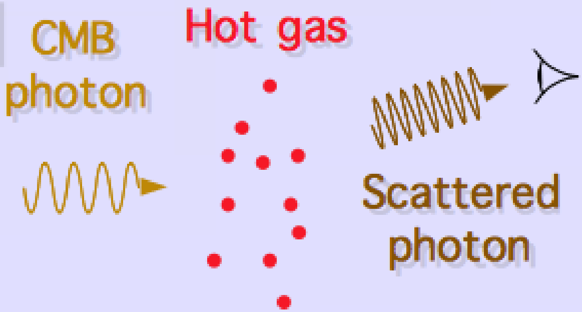
Hot gas structures

z>3 | 3>z>2 | 2>z>1 | 1>z>0

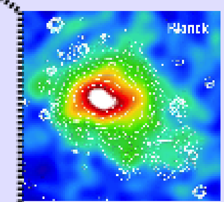




Detection : (Thermal) Sunyaev-Zel'dovich effect



Coma cluster



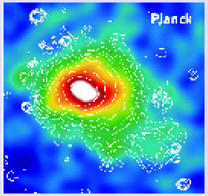
z=0.02

(+Bremsstrahlung in X-ray)

Hot gas structures

z>3 | 3>z>2 | 2>z>1 | 1>z>0

Coma cluster



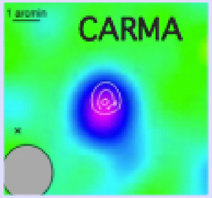
z=0.02

Catalogues of clusters (Planck, SPT, ACT...)

Hot gas structures

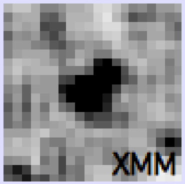
z>3 | 3>z>2 | 2>z>1 | 1>z>0

Mantz et al 2014



z=1.9

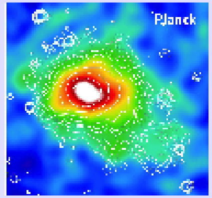
Gobat et al 2011



z=2.07

Catalogues of clusters (Planck, SPT, ACT...)

Coma cluster

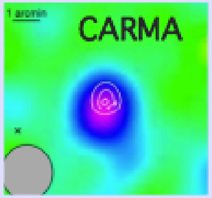


z=0.02

Hot gas structures

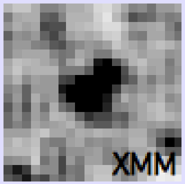
z>3 | 3>z>2 | 2>z>1 | 1>z>0

Mantz et al 2014



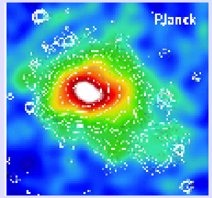
z=1.9

Gobat et al 2011



z=2.07

Coma cluster

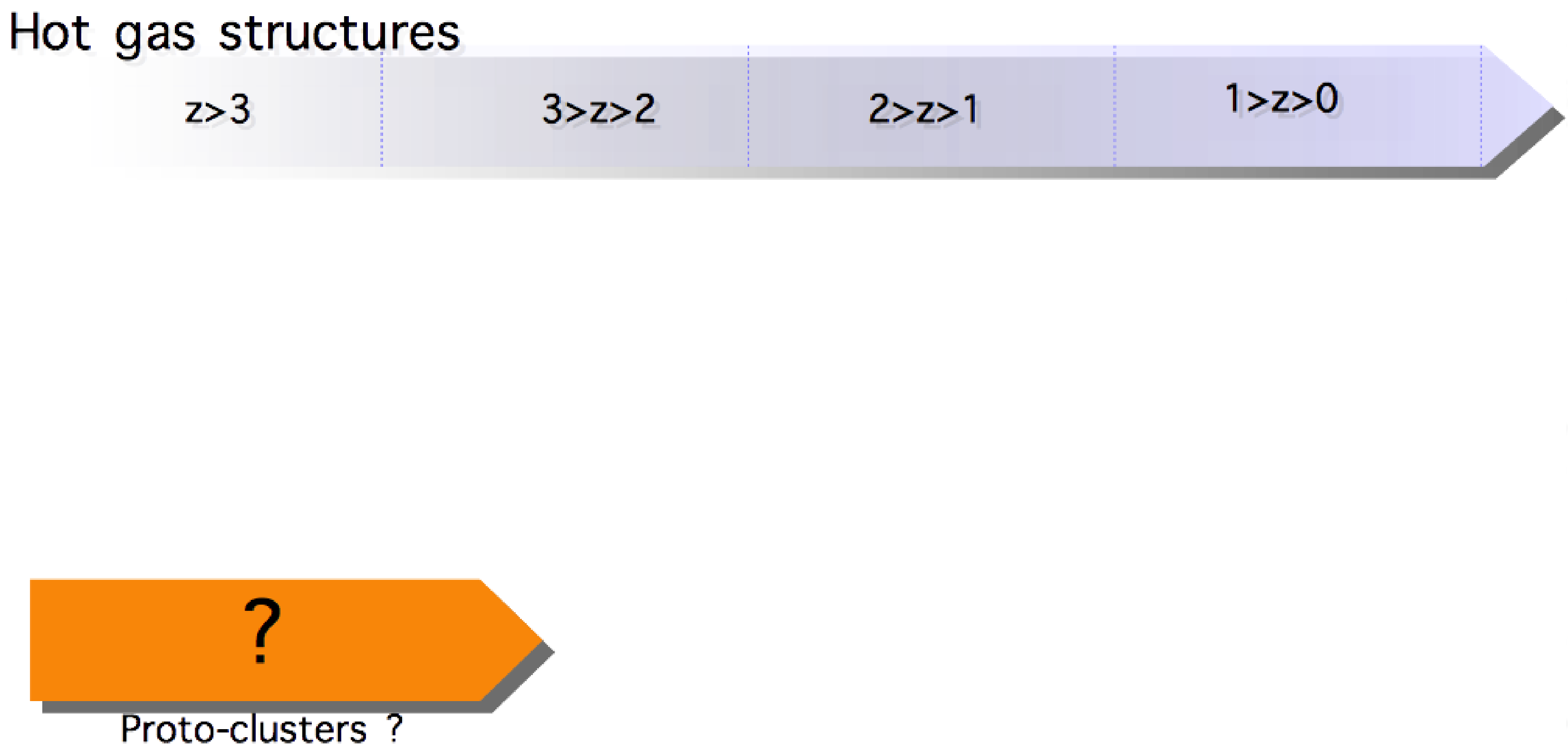


z=0.02

?

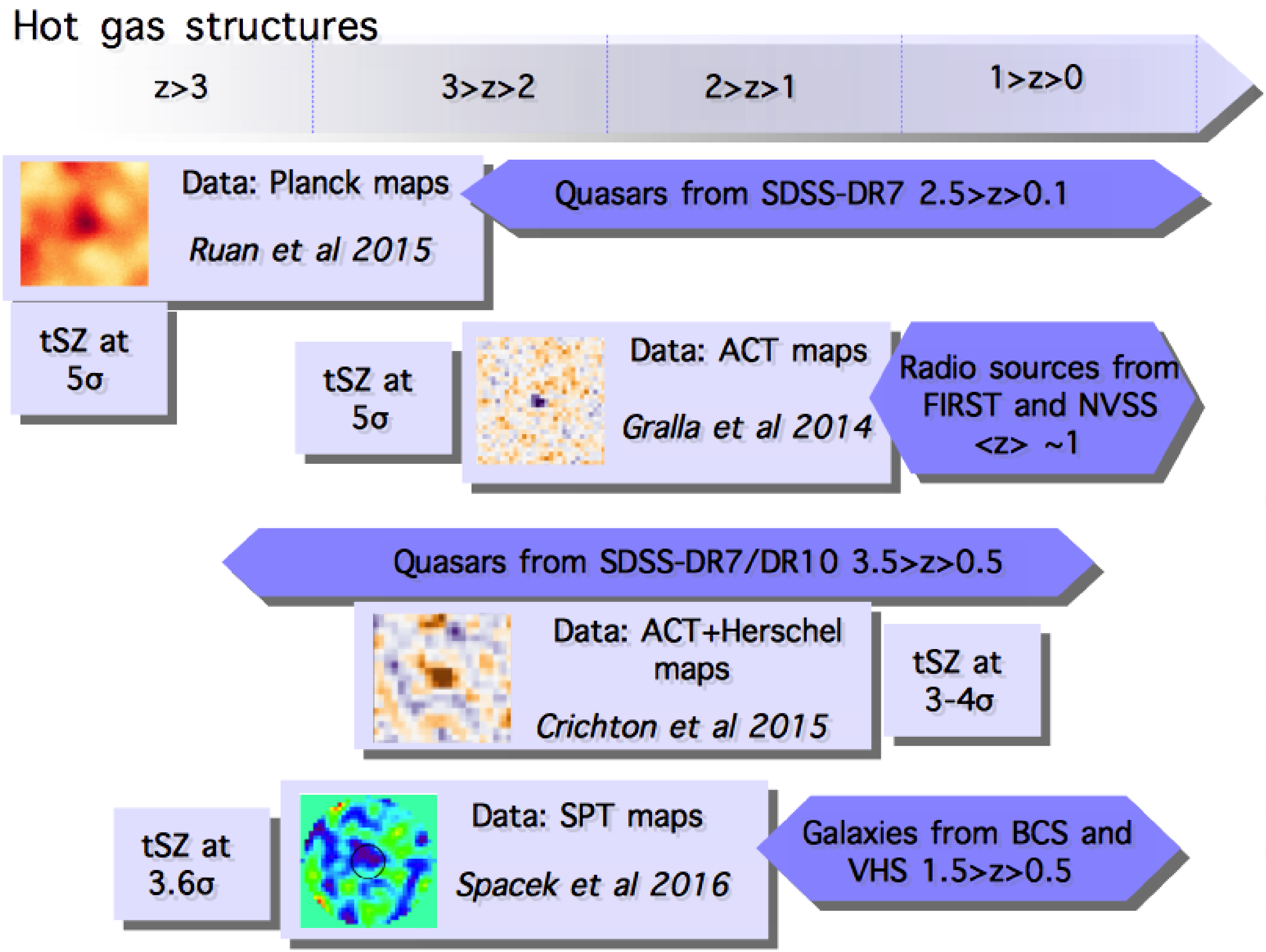
Proto-clusters ?

Catalogues of clusters (Planck, SPT, ACT...)



Detection of hot gas structures at high redshift? Millimeter maps + independent tracers.

An overview of the hot gas detection at high redshift

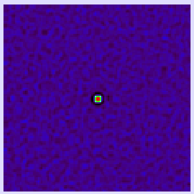


An overview of the hot gas detection at high redshift

Hot gas structures

z>3	3>z>2	2>z>1	1>z>0

Our tracers : Quasars from SDSS-DR12 5>z>0.1



Our data: Planck maps (70, 100, 143, 217, 353, 545 and 857 GHz)

Table of contents

A significant signal at QSO positions

Find a signal (1)

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

- Extract a flux at the position of the QSOs with a matched filter.
- To increase the signal-to-noise, work with the **average flux** for a given sample of QSOs.

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 (QSO and hot gas),
- $\vec{x}_0$ the QSO's position,
- $\tau_\nu(\vec{x})$ the spatial profile of the cluster (convolved with the Planck beam) and
- $n_\nu(\vec{x})$ the instrumental and astrophysical noise.

F_ν + errors extracted with a single-frequency matched filter.

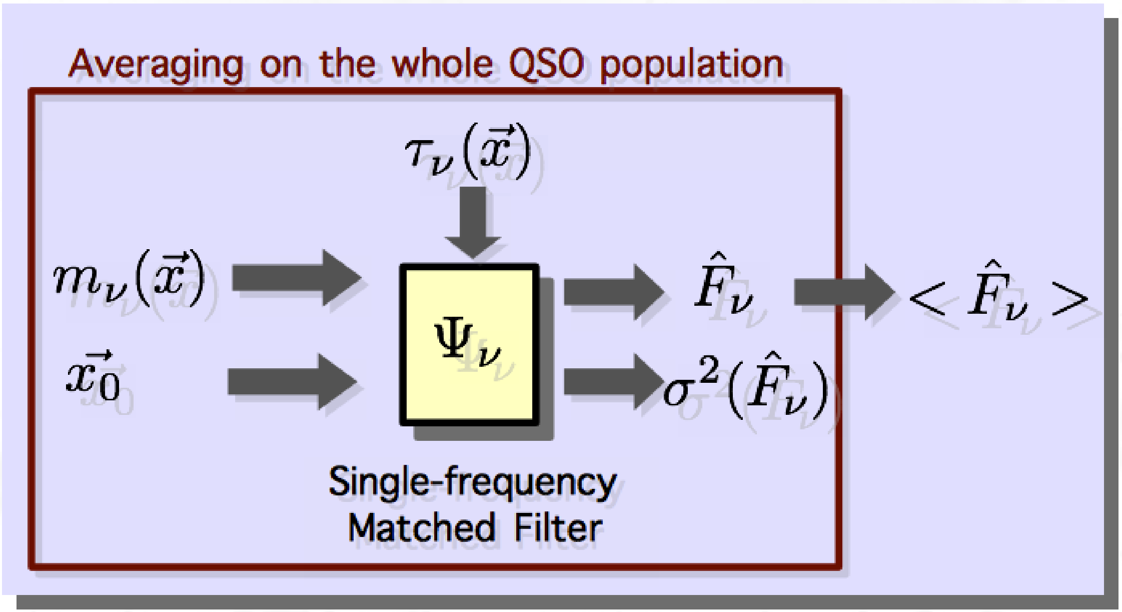
A significant signal at QSO positions

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 (QSO and hot gas),
- $\vec{x_0}$ the QSO's position,
- $\tau_\nu(\vec{x})$ the spatial profile of the cluster (convolved with the Planck beam) and
- $n_\nu(\vec{x})$ the instrumental and astrophysical noise.

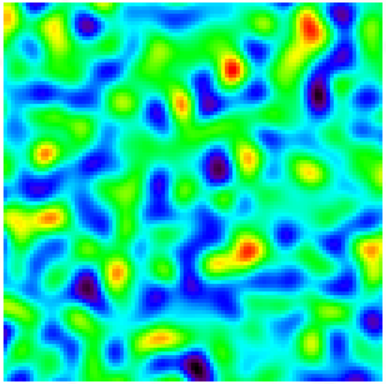
F_ν + errors extracted with a single-frequency matched filter.



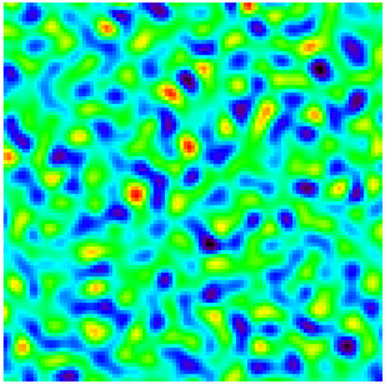
A significant signal at QSO positions

Average flux

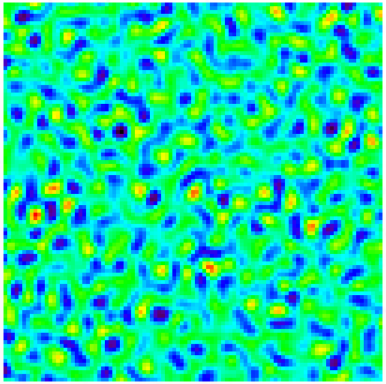
Average filtered maps centered on QSO positions. Size of the maps: $10^\circ \times 10^\circ$.



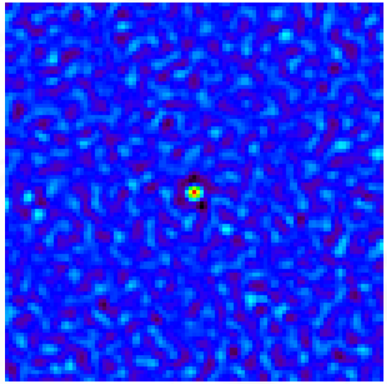
Average filtered map at 70 GHz



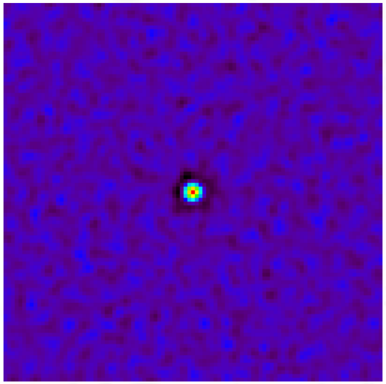
Average filtered map at 100 GHz



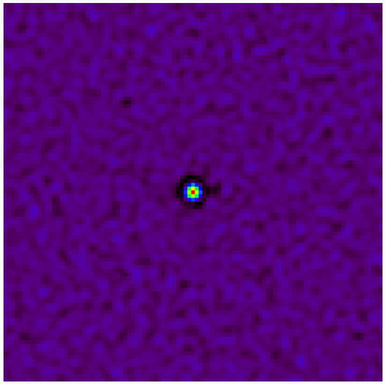
Average filtered map at 143 GHz



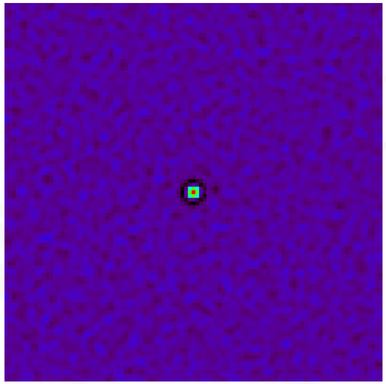
Average filtered map at 217 GHz



Average filtered map at 353 GHz

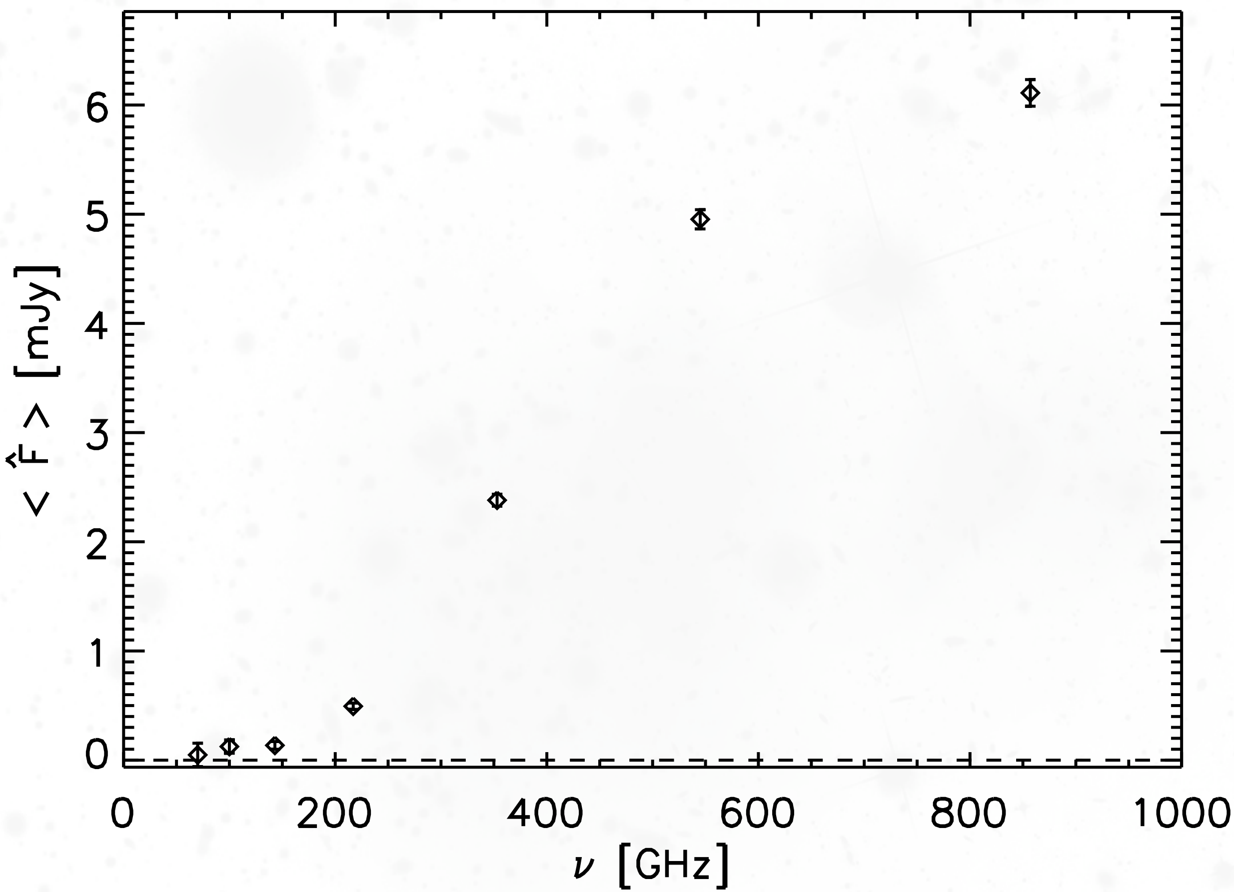


Average filtered map at 545 GHz



Average filtered map at 857 GHz

A significant signal at QSO positions



A significant signal at QSO positions

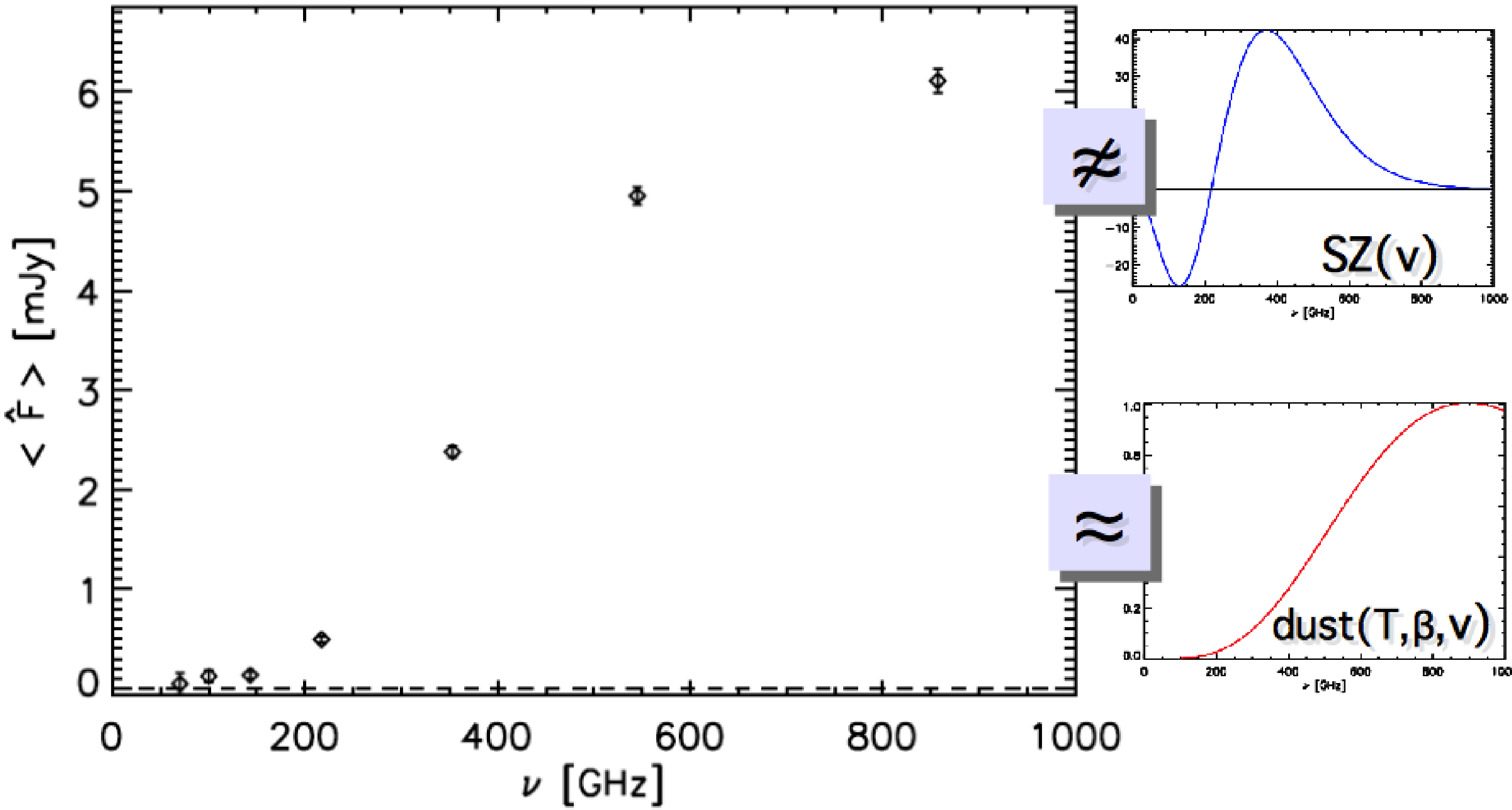


Table of contents

Find a signal (1) [DONE]

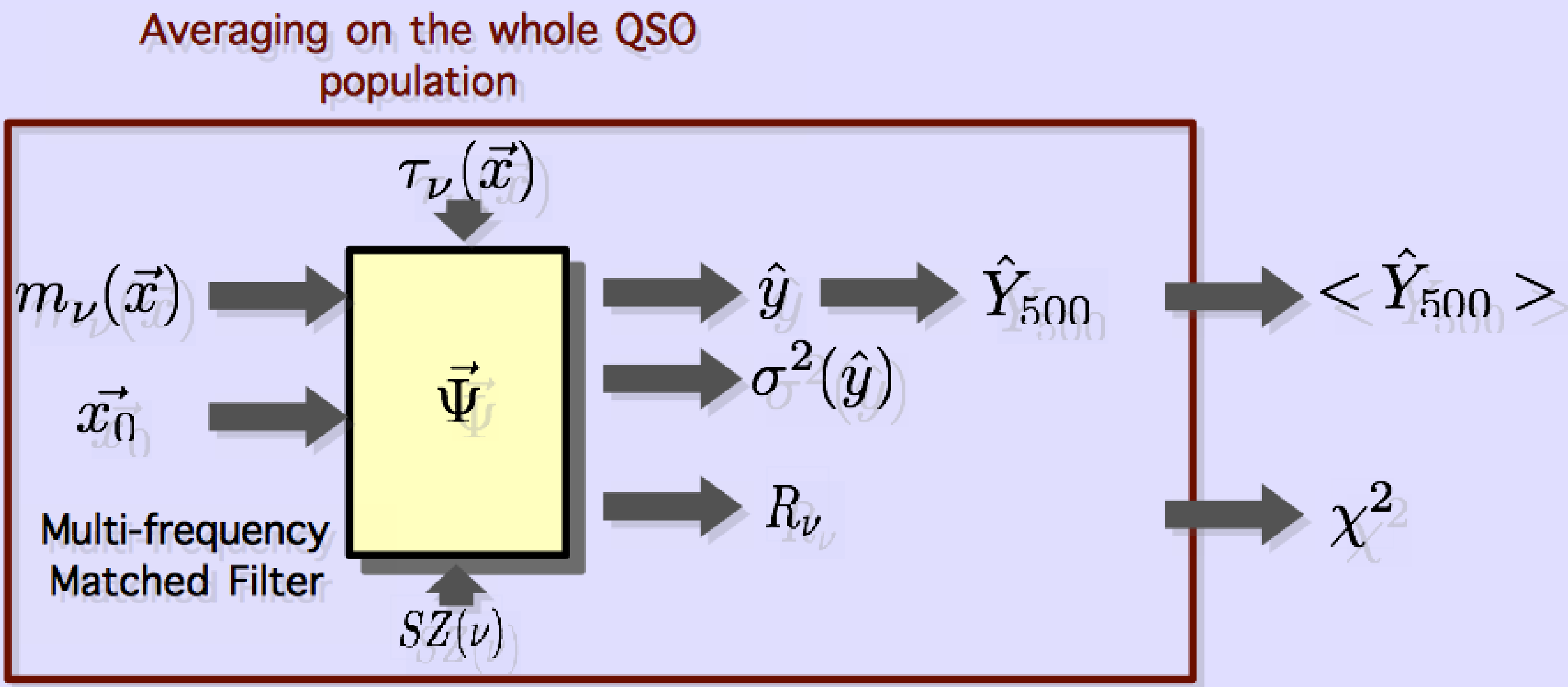
~~First step: what is the nature of the signal at QSO positions?~~

- ~~Extract a flux at the position of the QSOs with a matched filter.~~
- ~~To increase the signal-to-noise, work with the **average flux** for a given sample of QSOs.~~

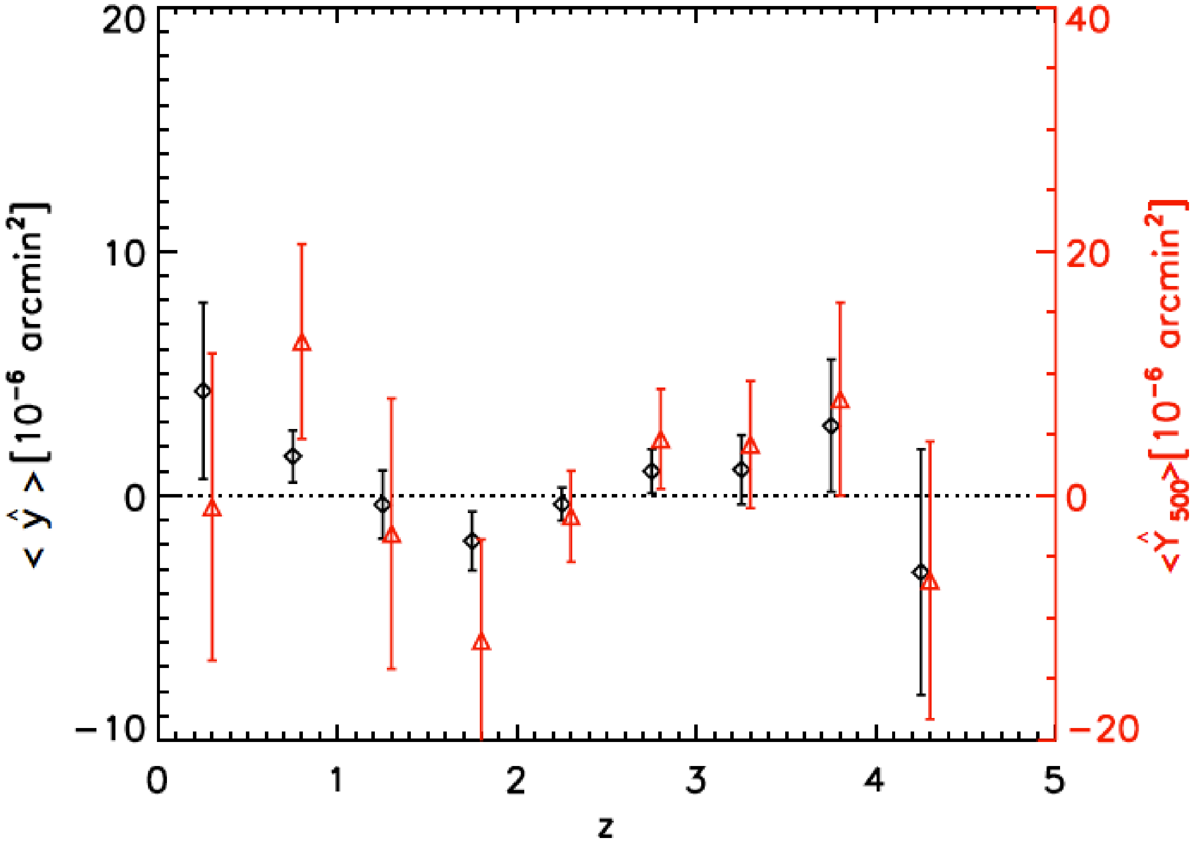
Find a signal (2)

Second step: assume the tSZ is the dominant signal and extract its amplitude.

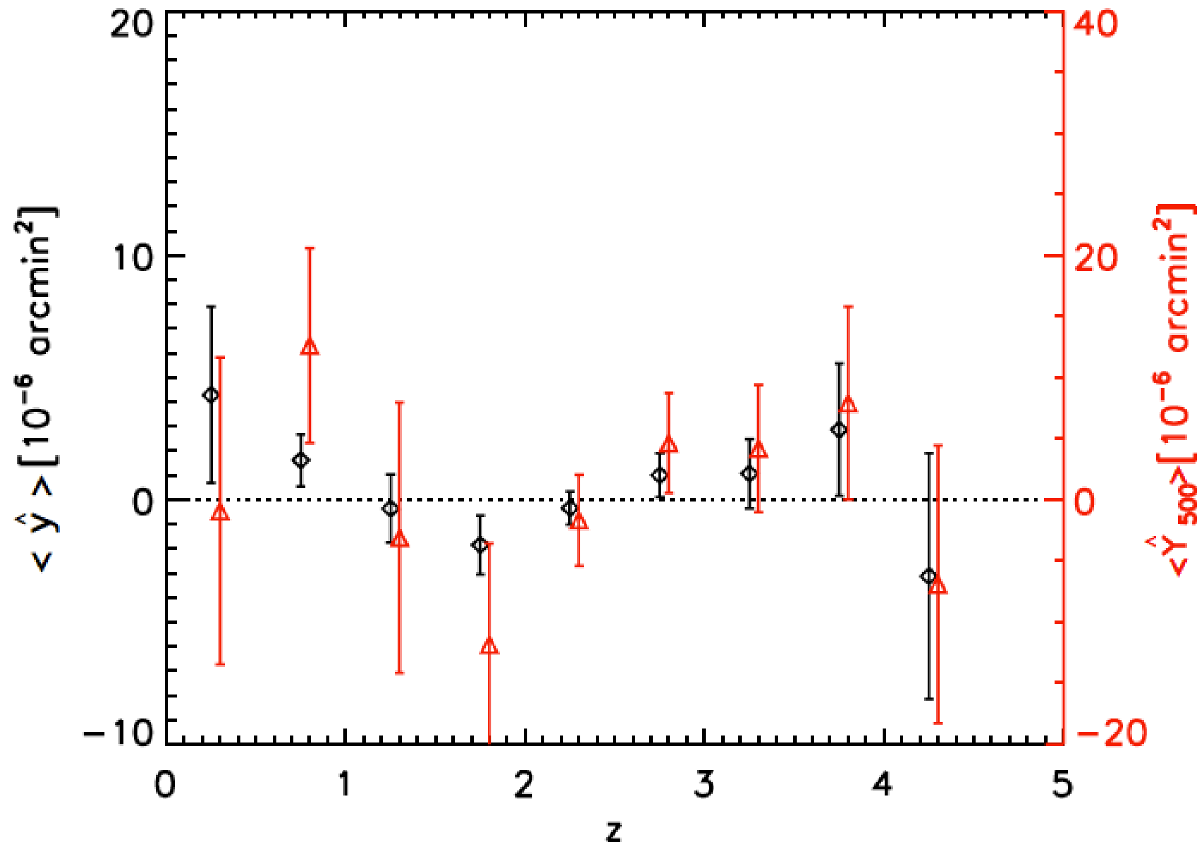
- Frequencies kept for the analysis: 100 GHz and 143 GHz (where tSZ is negative and dust emission is weaker).
- Assume $F_\nu = y \cdot SZ(\nu)$
- $Y_{500} = y \cdot E^{-2/3}(z) \cdot \left(\frac{D_A(z)^2}{500\text{Mpc}}\right) = f(M_{gas})$



$$R_\nu = \hat{F}_\nu - \hat{y} \cdot SZ(\nu)$$



20
10
0
−10
40
20
0
−20
0
1
2
3
4
5
z
< ŷ >[10⁻⁶ arcmin²]
<Ŷ 500>[10⁻⁶ arcmin²]



Higher frequencies required

- No significant tSZ signal detected.
- Need leverage at high frequency for removing dust.

Table of contents

Evidence for a tSZ signal for z>2 quasars

Find a signal (1) [DONE]

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

- ~~Extract a flux at the position of the QSOs with a matched filter.~~
- ~~To increase the signal-to-noise, work with the **average flux** for a given sample of QSOs.~~

Find a signal (2) [DONE]

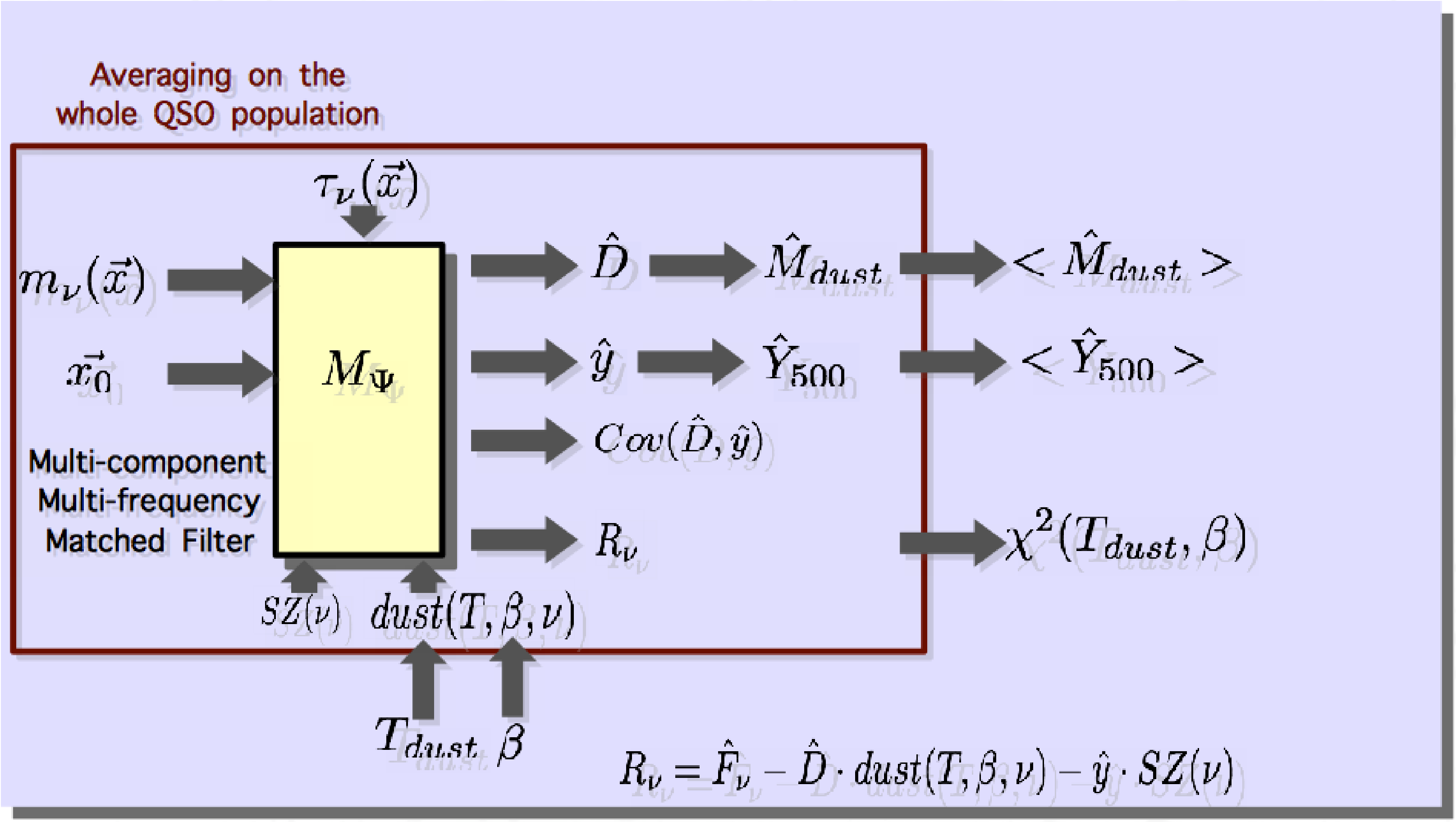
~~Second step: assume the tSZ is the dominant signal and extract its amplitude.~~

- ~~Frequencies kept for the analysis: 100 GHz and 143 GHz (where tSZ is negative and dust emission is weaker).~~
- ~~Assume $F_\nu = y \cdot SZ(\nu)$~~
- ~~$Y_{500} = y \cdot E^{-2/3}(z) \cdot \left(\frac{D_\mathrm{A}(z)^2}{500\mathrm{Mpc}}\right) = f(M_{gas})$~~

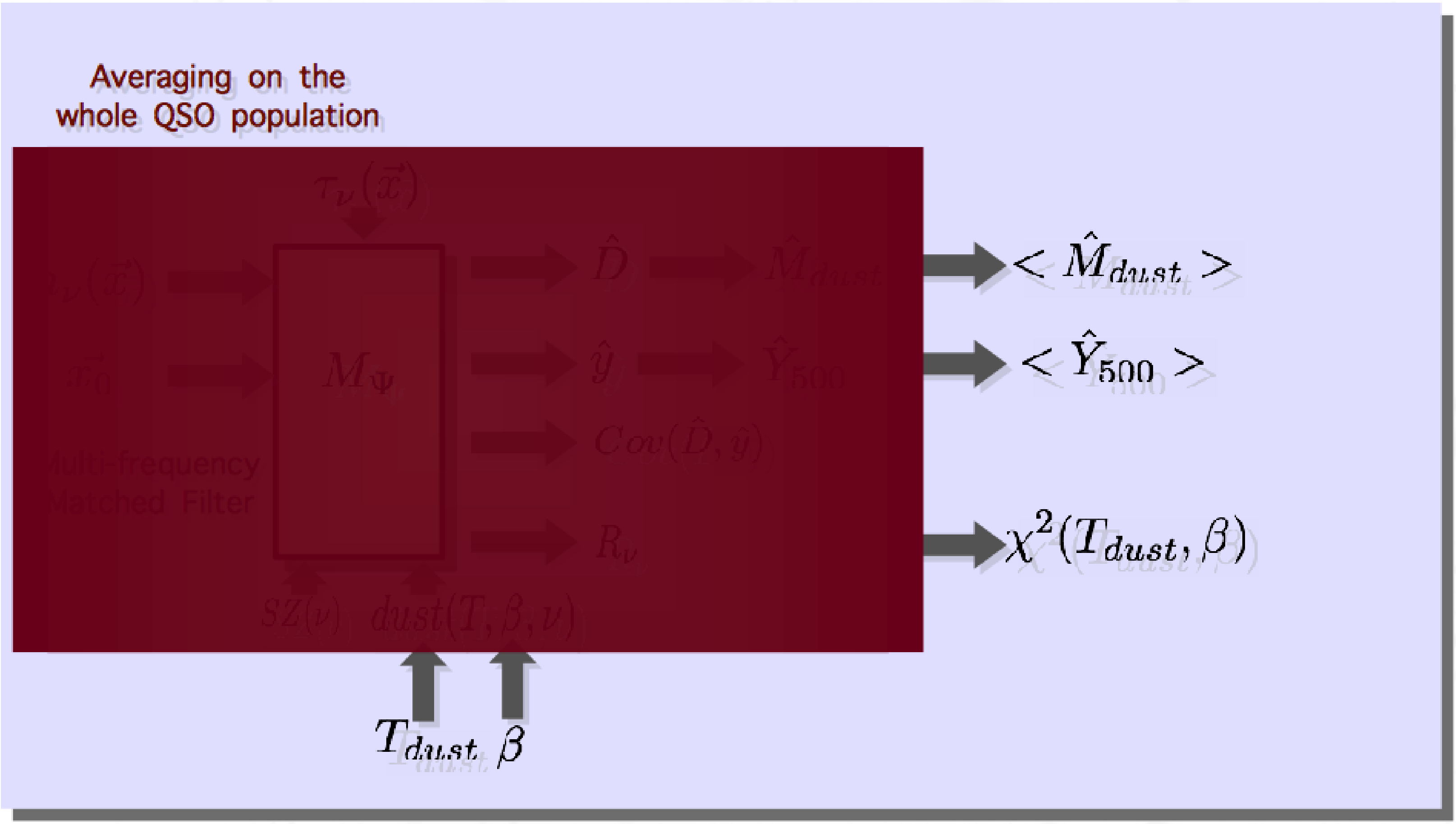
Find a signal (3)

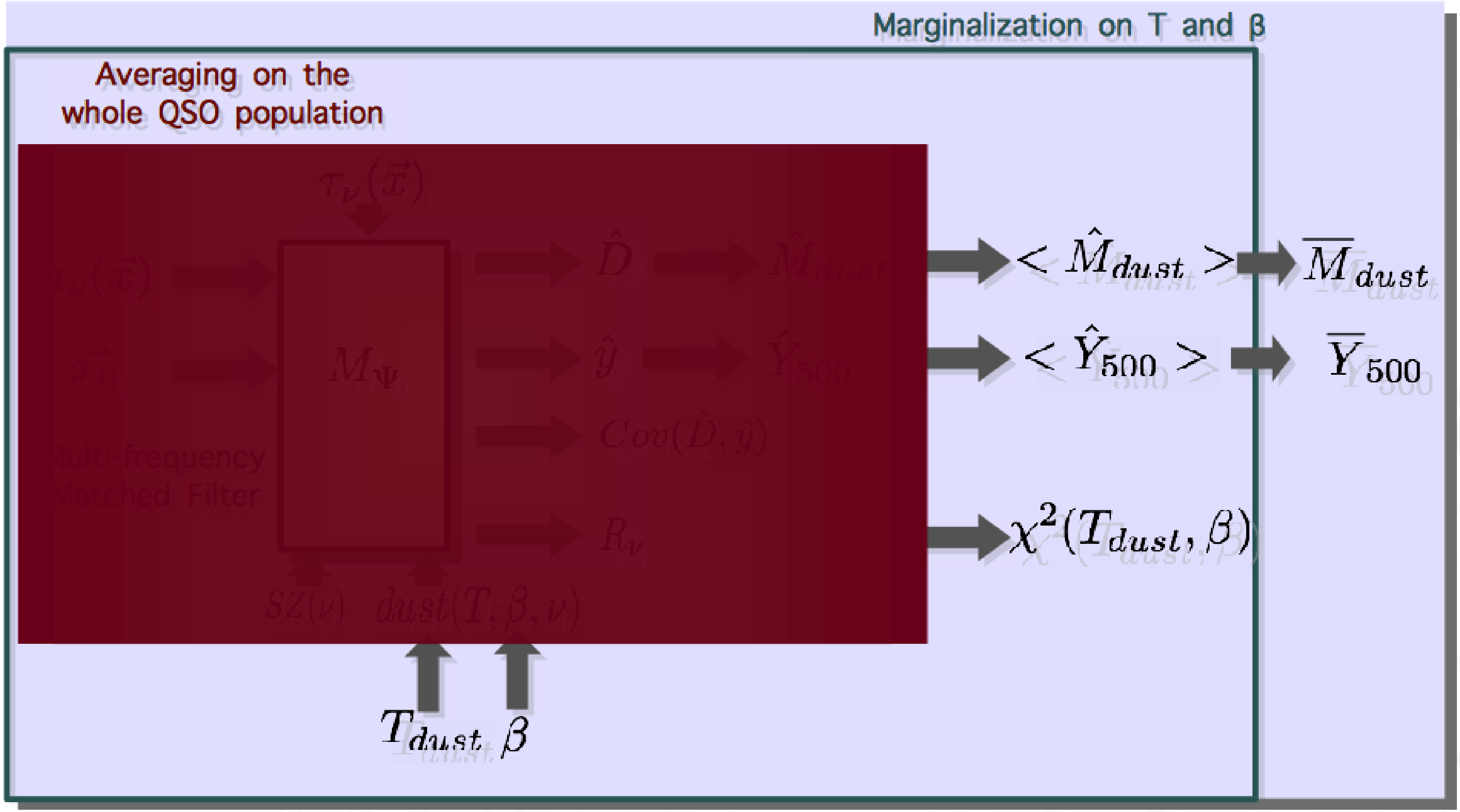
Third step: extract the dominant component of the signal, the dust emission and the sub-dominant tSZ signal.

- Assume $F_\nu = D \cdot dust(T_{dust}, \beta, \nu) + y \cdot SZ(\nu)$ with $dust(T_{dust}, \beta, \nu) = \nu^\beta \cdot B_\nu(T_{dust})$.
- $M_\mathrm{dust} = f(T_{dust}, \beta, D, z)$ (Beelen et al 2006)

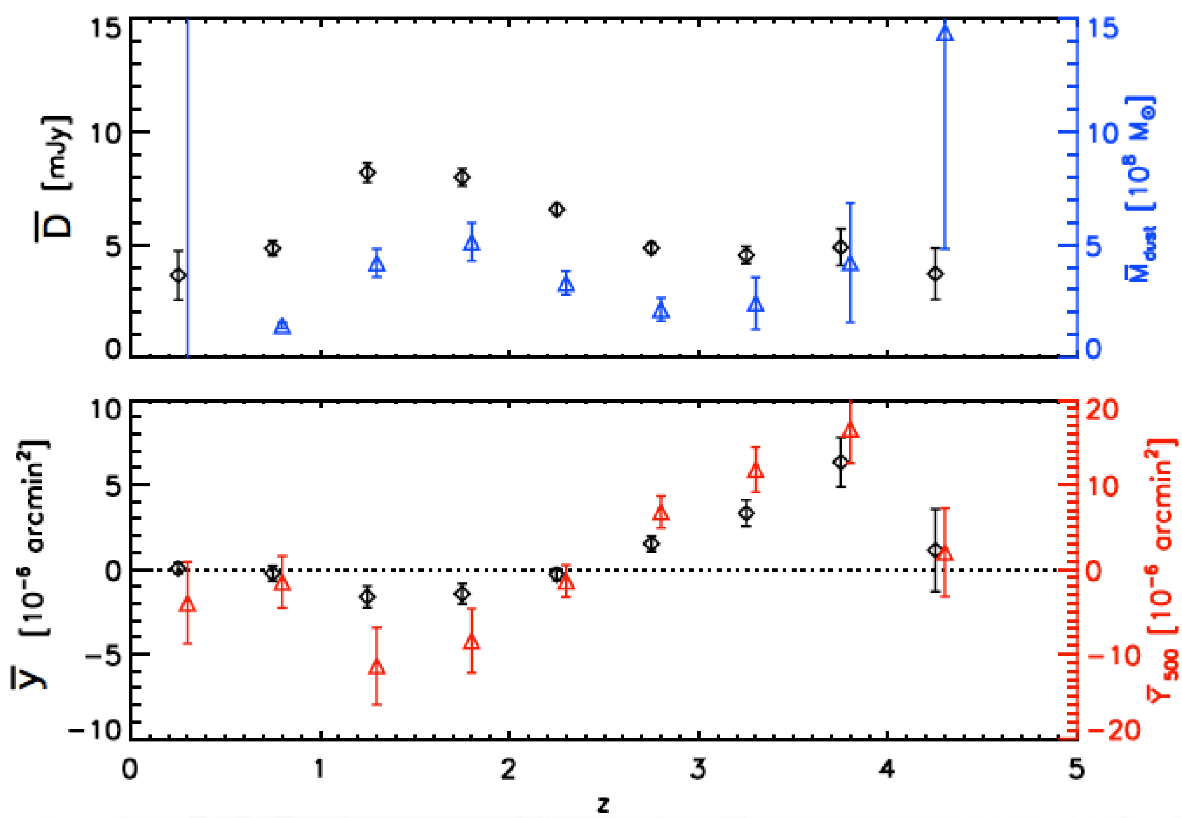

Averaging on the
whole QSO population
$\tau_\nu(\vec{x})$
$m_\nu(\vec{x})$
$\vec{x_0}$
M_Ψ
Multi-component
Multi-frequency
Matched Filter
$SZ(\nu)$
$dust(T,\beta,\nu)$
T_{dust}
β
$\hat{D}$
$\hat{M}_{dust}$
$< \hat{M}_{dust} >$
$\hat{y}$
$\hat{Y}_{500}$
$< \hat{Y}_{500} >$
$Cov(\hat{D},\hat{y})$
R_ν
$\chi^2(T_{dust},\beta)$
$R_\nu = \hat{F}_\nu - \hat{D} \cdot dust(T,\beta,\nu) - \hat{y} \cdot SZ(\nu)$

Evidence for a tSZ signal for z>2 quasars

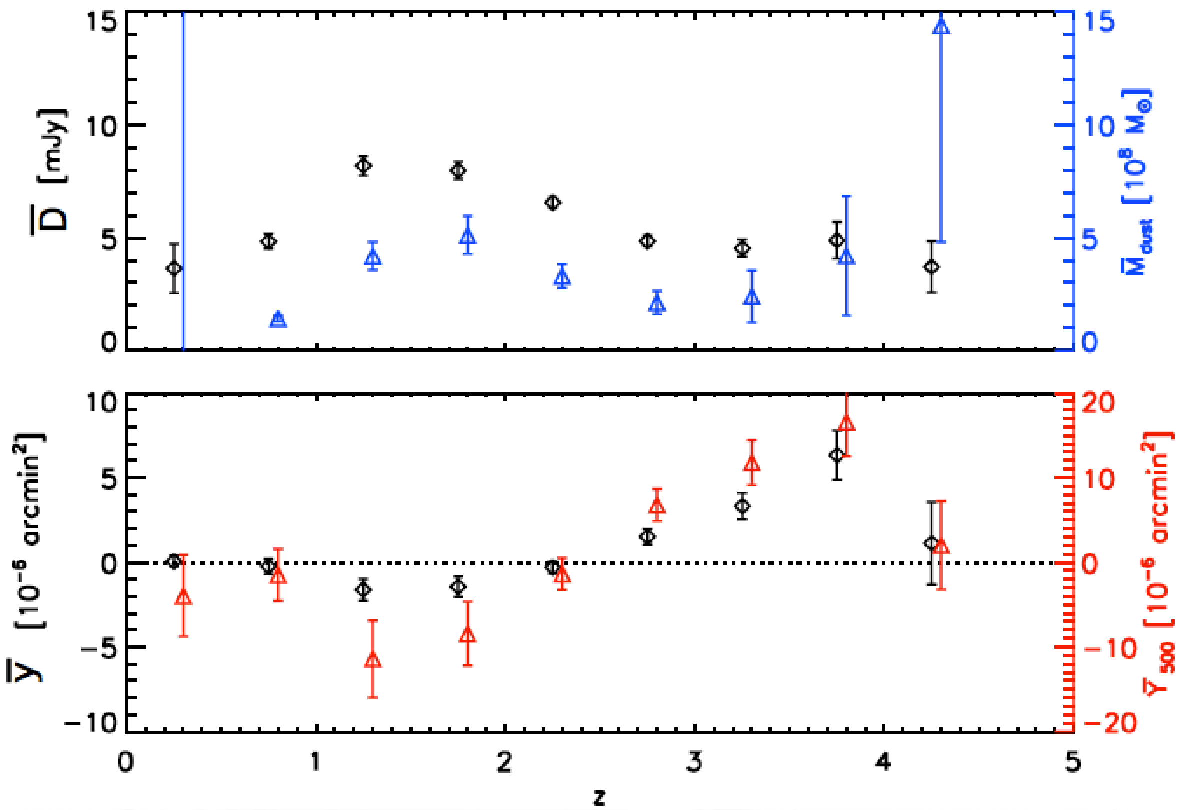



Marginalization on T and β
Averaging on the whole QSO population
[redacted]
$< \hat{M}_{dust} >$
$\overline{M}_{dust}$
$< \hat{Y}_{500} >$
$\overline{Y}_{500}$
$\chi^2(T_{dust}, \beta)$
T_{dust} β

Evidence for a tSZ signal for z>2 quasars



Evidence for a tSZ signal for z>2 quasars



Interesting sub-population of QSO : $z \in [2.5, 4.]$, no radio counterpart (from FIRST)

- Significant signal from the hot gas: $Y_{500} = (10.86 \pm 1.46) \times 10^{-6} \text{arcmin}^2$ (7 σ).
- Cluster mass estimated at $1.71 \pm 0.13 h^{-1} 10^{13} \text{M}_\odot$ (assuming tSZ from virialized clusters and standard redshift evolution). Consistent with the QSO clustering analysis $1.41 \pm 0.6 h^{-1} 10^{13} \text{M}_\odot$ (Richardson et al 2012).

Table of contents

Conclusion

Evidence for hot gas in high redshift structures

- Significant signal at QSO positions in the Planck maps.
- Signal dominated by dust emission.
- Evidence for a sub-dominant tSZ signal using the radio quiet sub-sample between $2.5<z<4$.
- No tSZ signal is found if the analysis is restricted to low frequency ($\nu<217$ GHz) maps.
- High frequencies ($\nu>217$GHz) are required to disentangle dust emission from tSZ.

Conclusion

Evidence for hot gas in high redshift structures

- Significant signal at QSO positions in the Planck maps.
- Signal dominated by dust emission.
- Evidence for a sub-dominant tSZ signal using the radio quiet sub-sample between $2.5<z<4$.
- No tSZ signal is found if the analysis is restricted to low frequency ($\nu<217$ GHz) maps.
- High frequencies ($\nu>217$GHz) are required to disentangle dust emission from tSZ.

Origin of the tSZ signal difficult to determine

- Hot gas gravitationally heated in potential wells of QSO halos? Or gas from AGN feedback?
- Proper modeling of the AGN required to decide between the two hypotheses.

Conclusion

Evidence for hot gas in high redshift structures

- Significant signal at QSO positions in the Planck maps.
- Signal dominated by dust emission.
- Evidence for a sub-dominant tSZ signal using the radio quiet sub-sample between $2.5<z<4$.
- No tSZ signal is found if the analysis is restricted to low frequency ($\nu<217$ GHz) maps.
- High frequencies ($\nu>217$GHz) are required to disentangle dust emission from tSZ.

Origin of the tSZ signal difficult to determine

- Hot gas gravitationally heated in potential wells of QSO halos? Or gas from AGN feedback?
- Proper modeling of the AGN required to decide between the two hypotheses.

Low mass halos contamination

Understanding the mixture of components (tSZ, dust, etc) in low mass halos ($M \sim 10^{13} M_{\odot}$) may be important to understand the selection function of future millimeter surveys (CMB-S4, COrE+, ?).

Thanks for your attention!