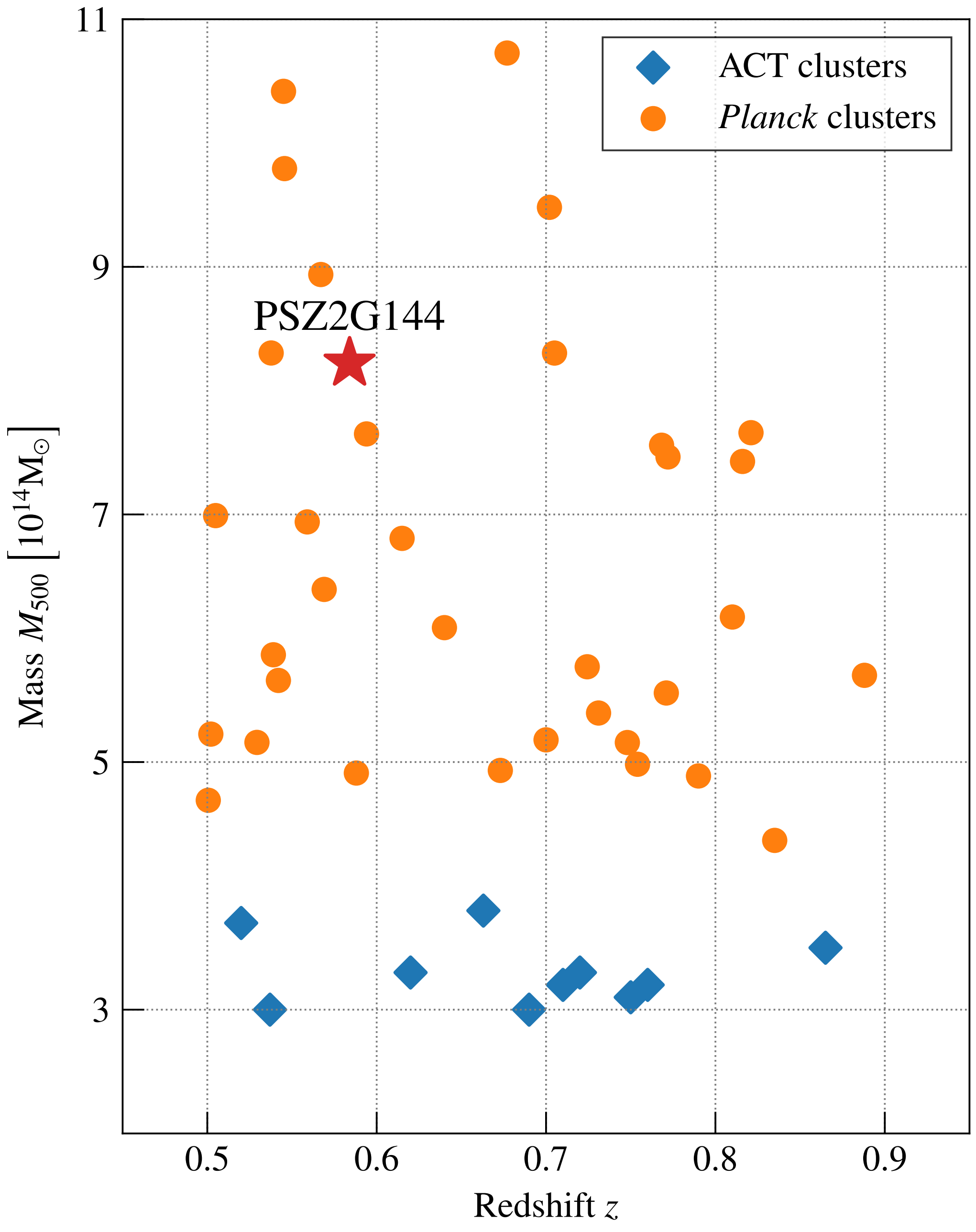
ACT-CL J0215.4+0030: a test case of faint galaxy clusters within the NIKA2 SZ large program

Florian Kéruzoré, LPSC, Grenoble,
on behalf of the NIKA2 collaboration

mmUniverse@NIKA2 2019

Context: previous NIKA2 LPSZ analysis



So far, only one LPSZ cluster analysis published:

PSZ2-G144.83+25.11 (F. Ruppin *et al.*, A&A 2018)

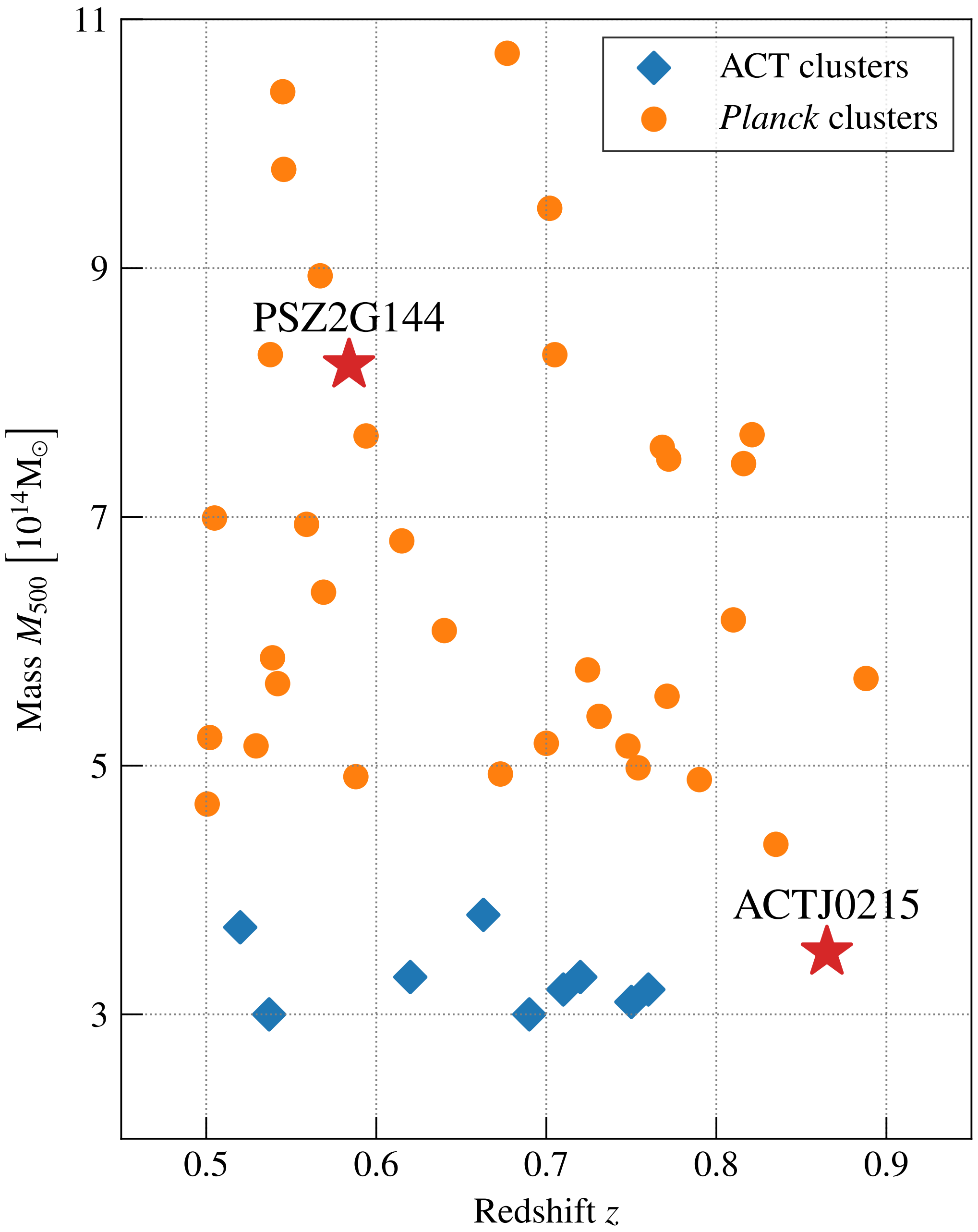
- Massive : $M_{Planck} = 8.22 \times 10^{14}\,M_{\odot}$
- Low redshift : $z = 0.58$
- $t_{obs} = 5.5 \times t_{LPSZ} = 11$ h

→ Great for NIKA2 science verification

→ Next analysis: go for a fainter cluster?

Choice of next target

NIKA2



Best candidate: **ACT-CL J0215.4+0030**

- Low mass: $M_{ACT} = 3.8 \times 10^{14}\ M_\odot$
- High redshift: $z = 0.87$
- $t_{obs} = t_{LPSZ} = 9$ h

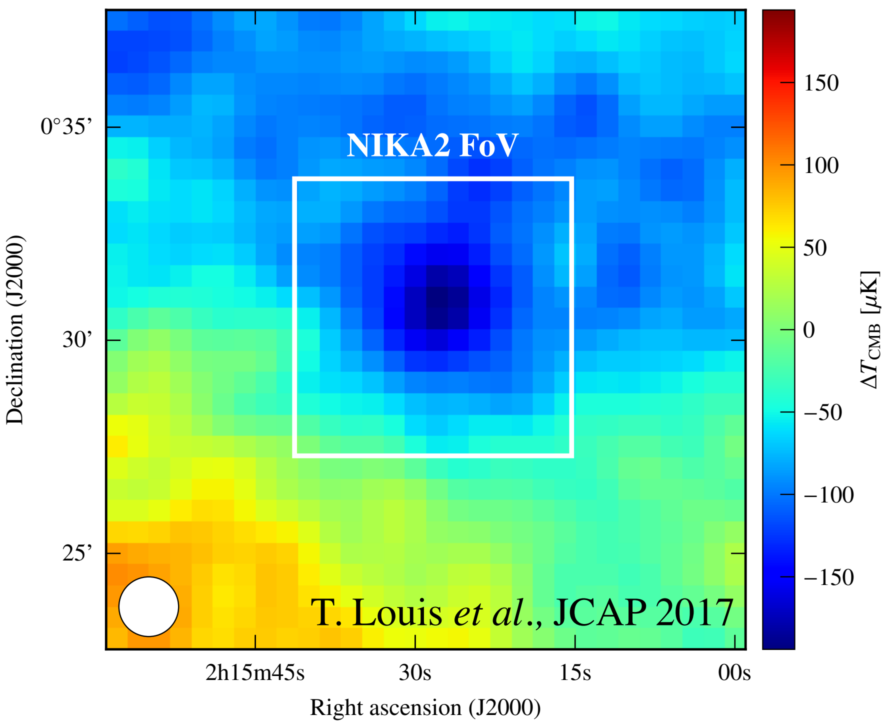
→ We expect a smaller, fainter cluster

→ Assess the NIKA2 performance on an “extreme” cluster of the LPSZ sample:

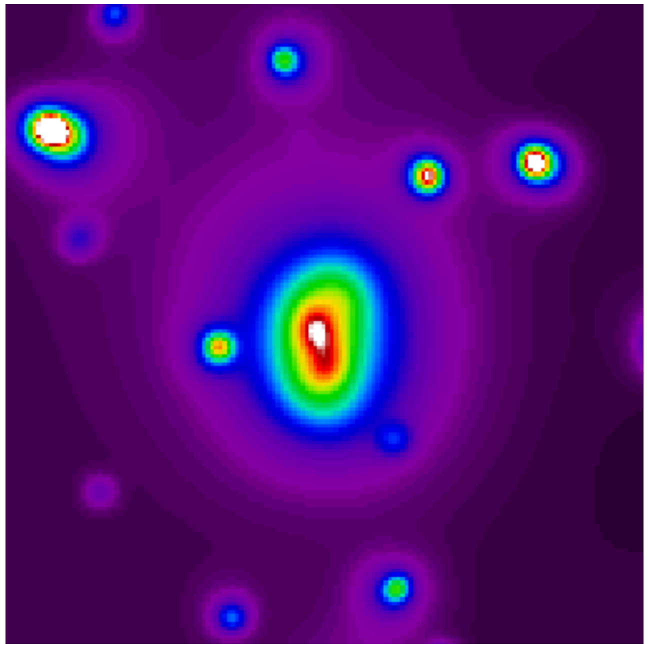
  - How hard will data reduction be?
  - What will thermodynamic properties look like?

Prior knowledge of the cluster

ACTPol 148 GHz map of the cluster

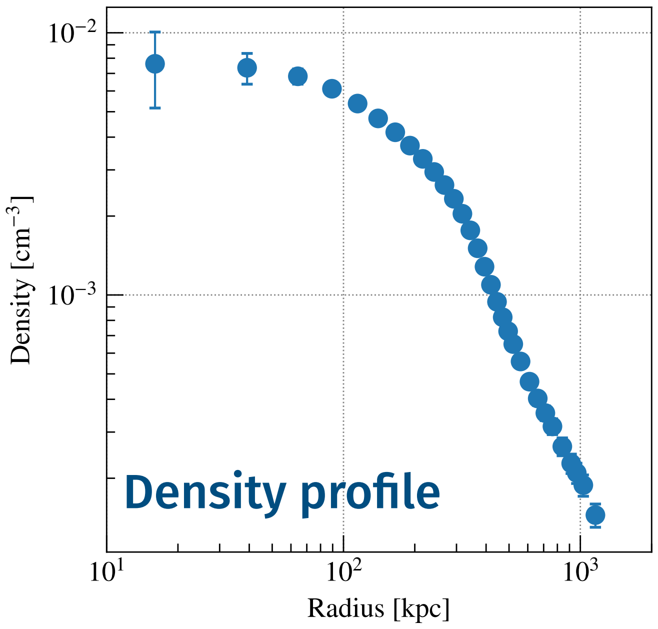


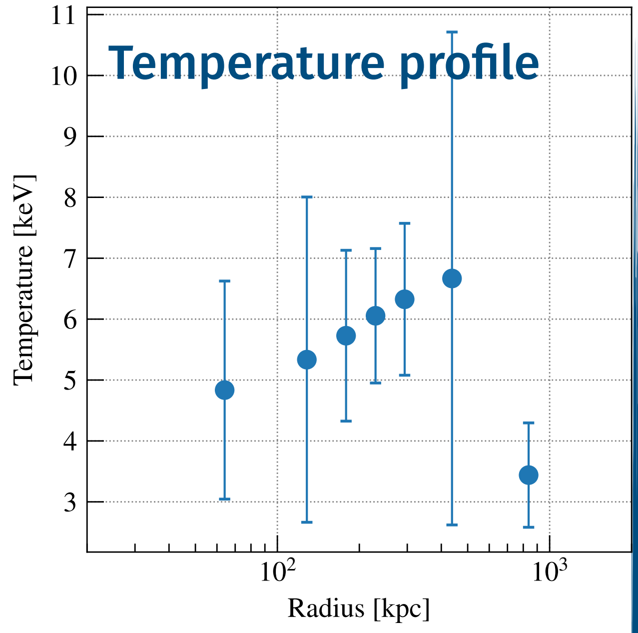
XMM view of the cluster

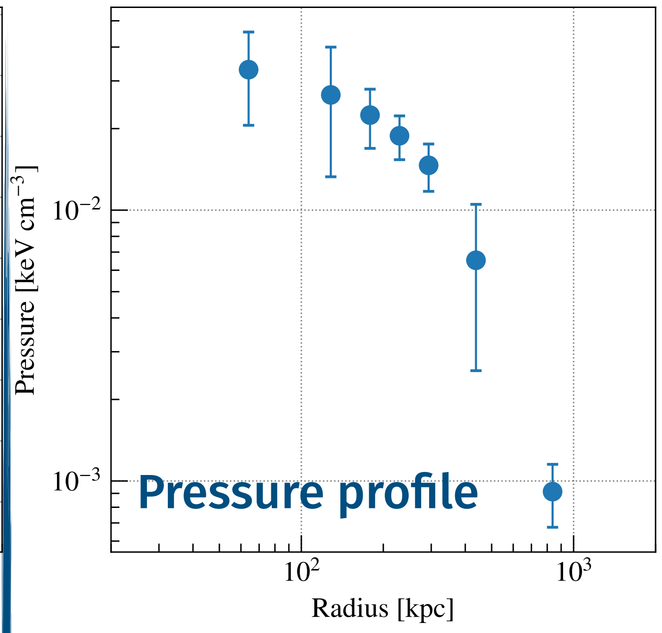


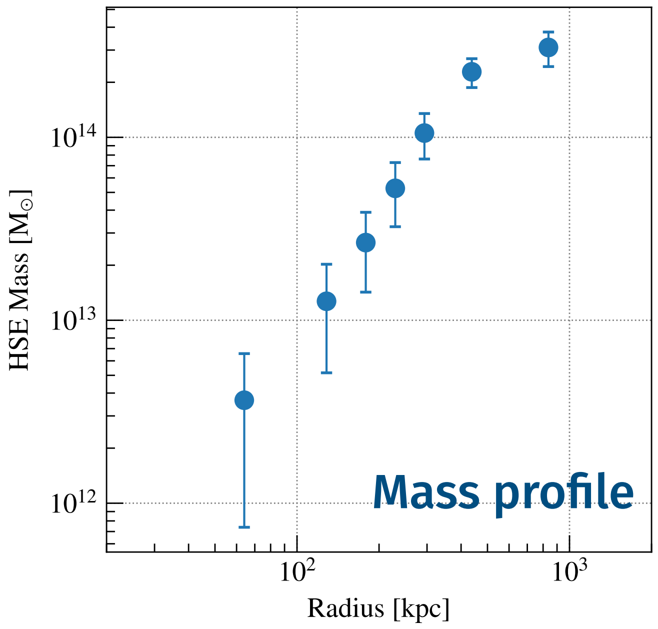
- High quality XMM data for a high redshift cluster (z=0.87)
- Few objects at that redshift have X spectroscopy data
- $t_{obs,XMM} \approx 35$ ks

XMM profiles (with spectroscopic information)







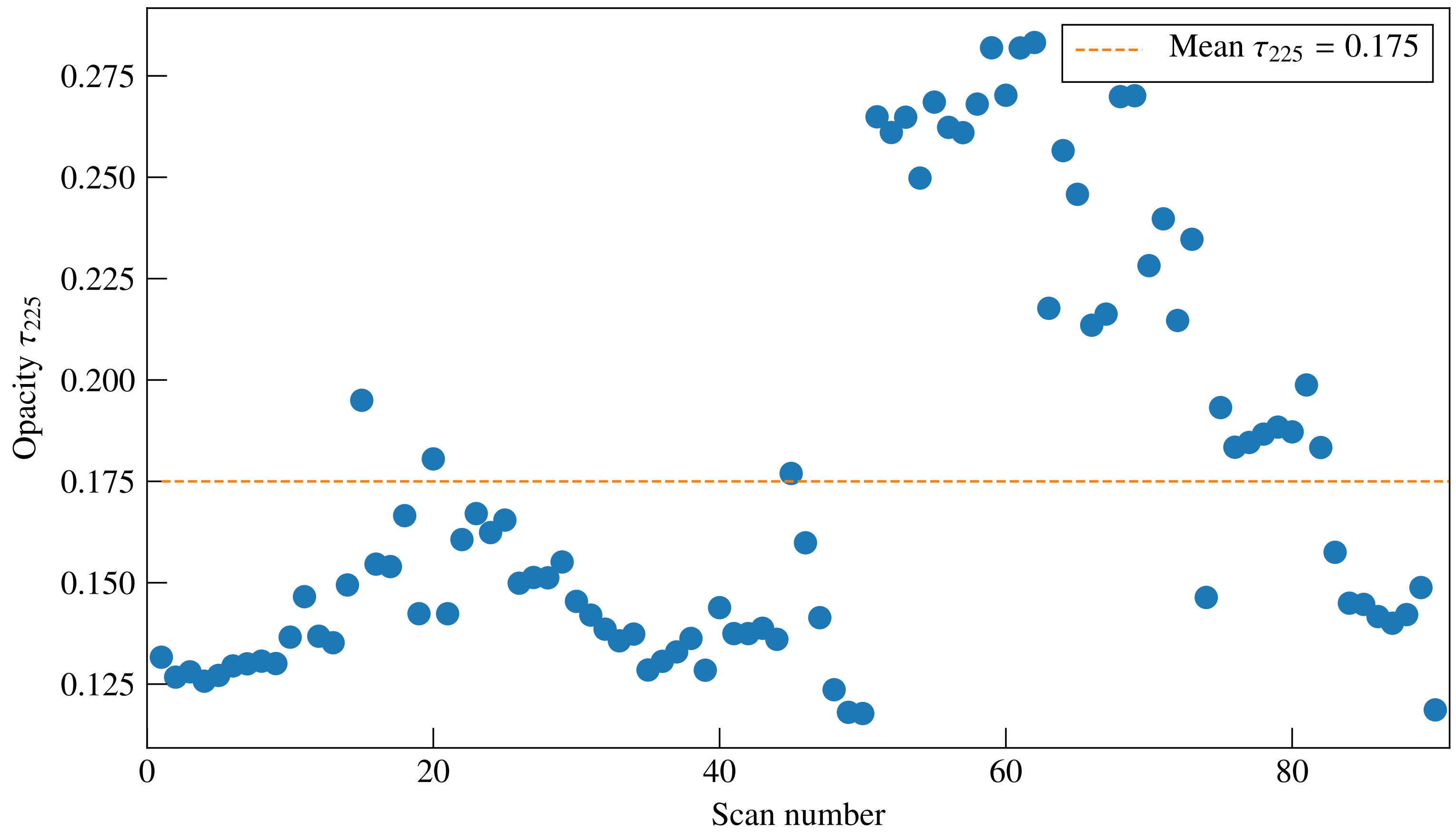


To be compared with SZ products

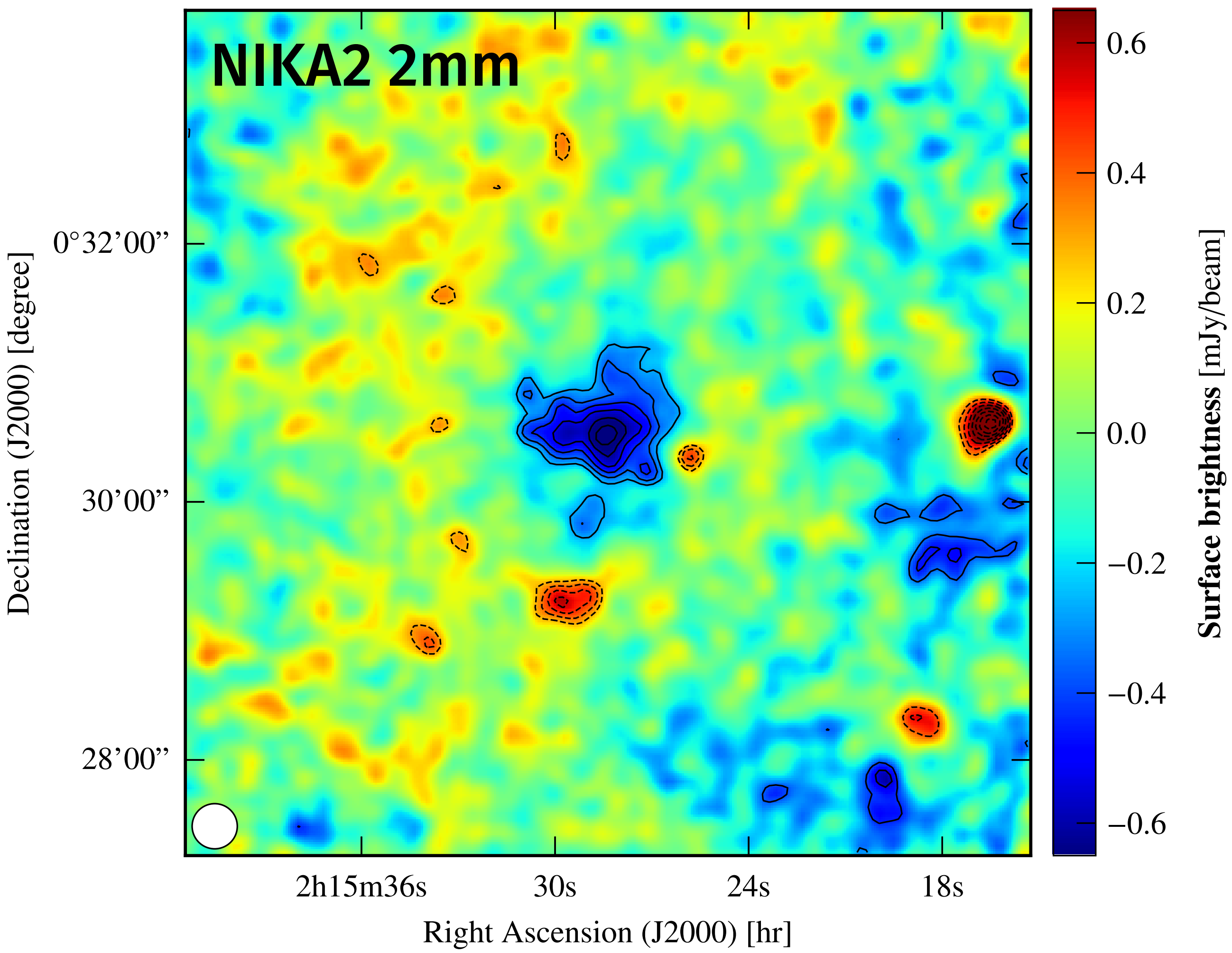
NIKA2 observations of the cluster

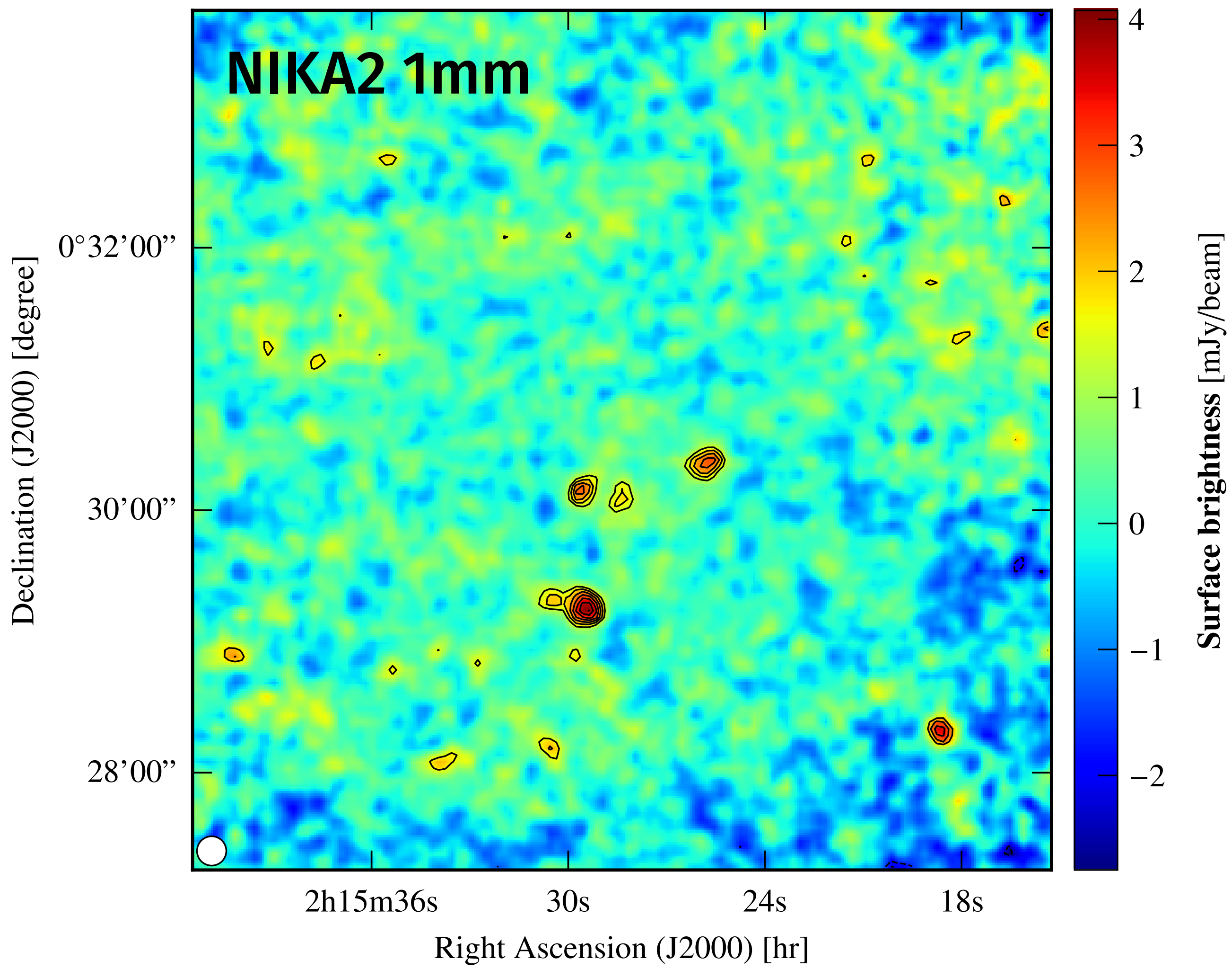
- Cluster observed for 9h during the 14th NIKA2 run (N2R14, Jan. 16-23 2018)
- Atmospheric condition during the observations: average ($\tau_{225} \in [0.1, 0.3]$)

τ_{225} (atmospheric opacity at 225 GHz) for ACTJ0215 scans:



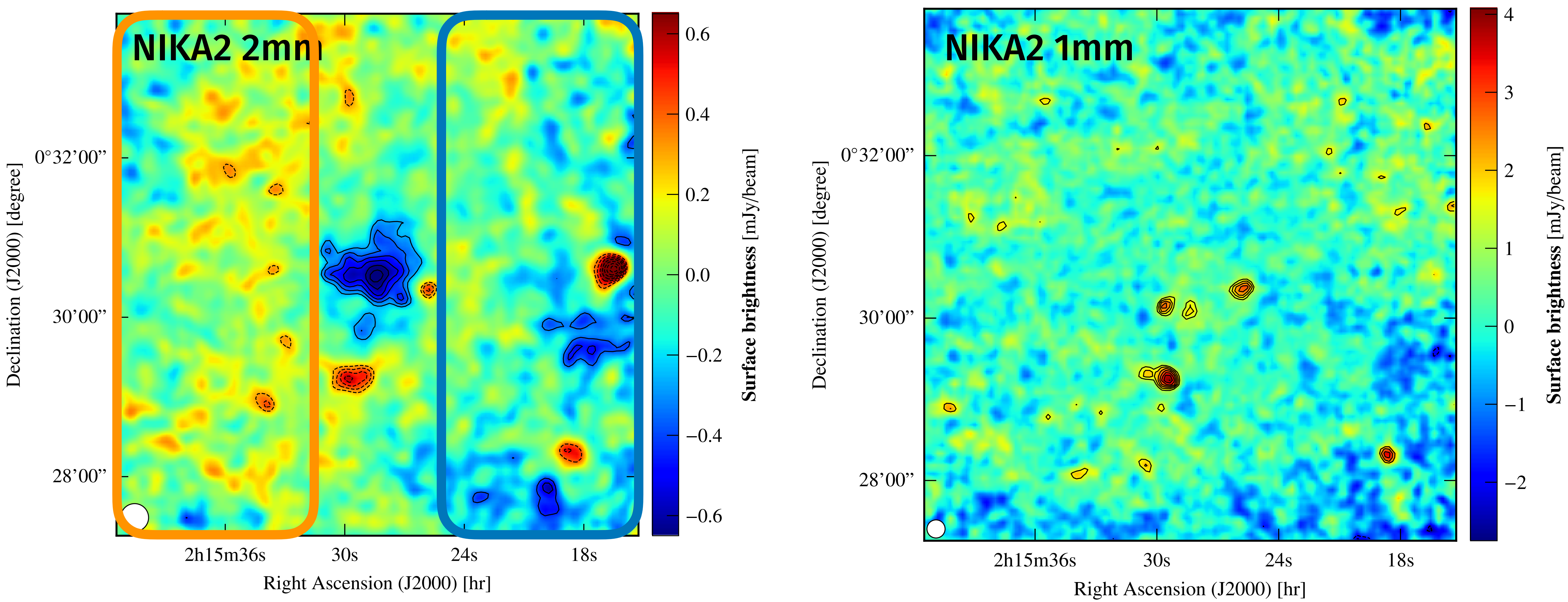
→ Average conditions for Pico Veleta winter observations





- **Peak SNR: 7.8σ** (black contours = 1σ increments, starting from 2)

NIKA2 maps of the cluster



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- Large noise structures surrounding the cluster

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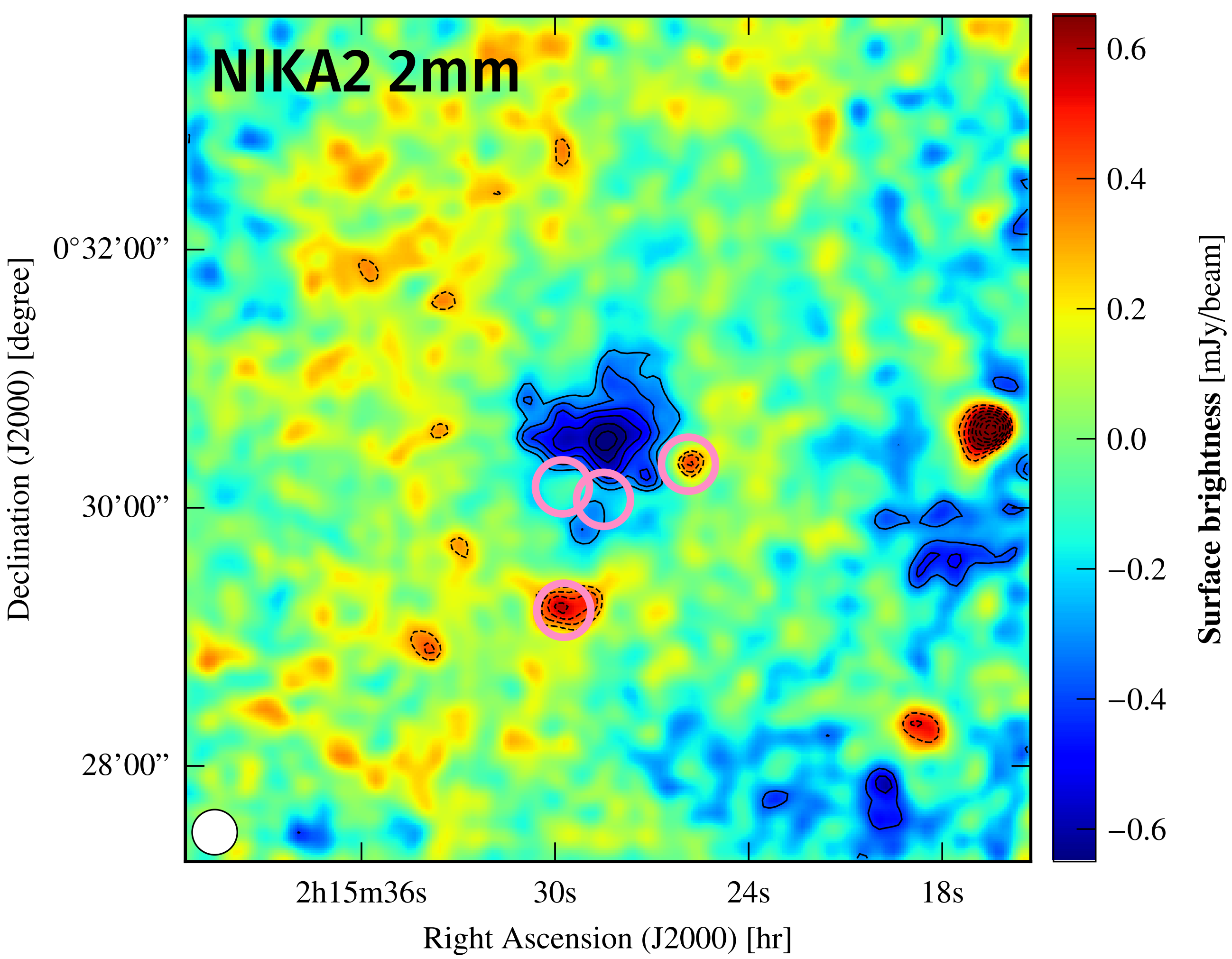

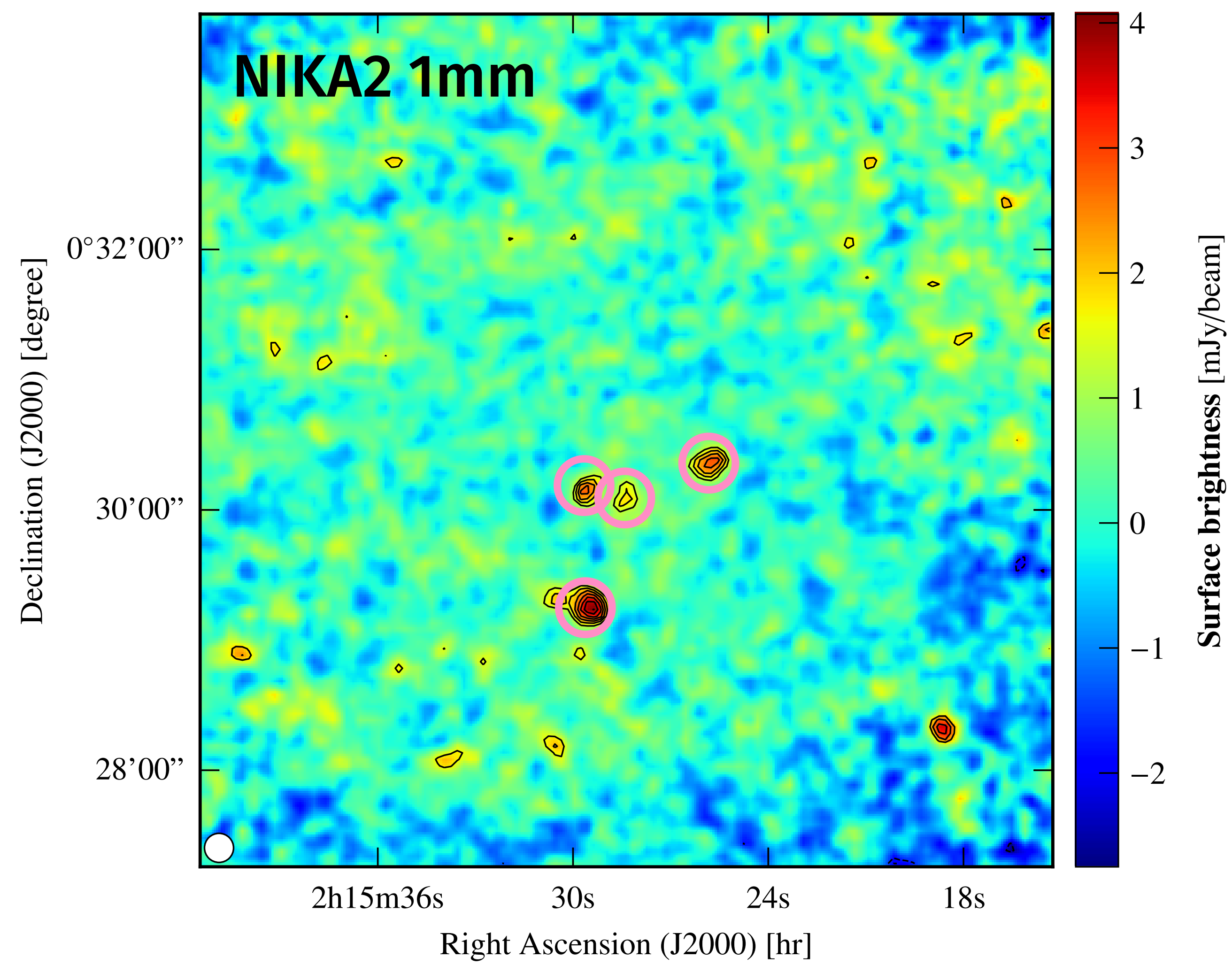

- **Peak SNR: 7.8σ** (black contours = 1σ increments, starting from 2)
- Large noise structures surrounding the cluster
- Strong point-sources contamination ("holes" in the cluster: positive signal compensating the SZ decrement)

Challenges of the analysis

From the maps, we identify two problems with the data:

1. **The noise structures:** need to find a better way to remove ("decorrelate") noise in the map;
2. **The point-sources:** need to know how our signal is affected by contamination
   - How can we remove them?
   - Impact on thermodynamic results?

Outline

Introduction & context

Remaining noise in the maps

Point-sources contamination

Thermodynamics of the ICM

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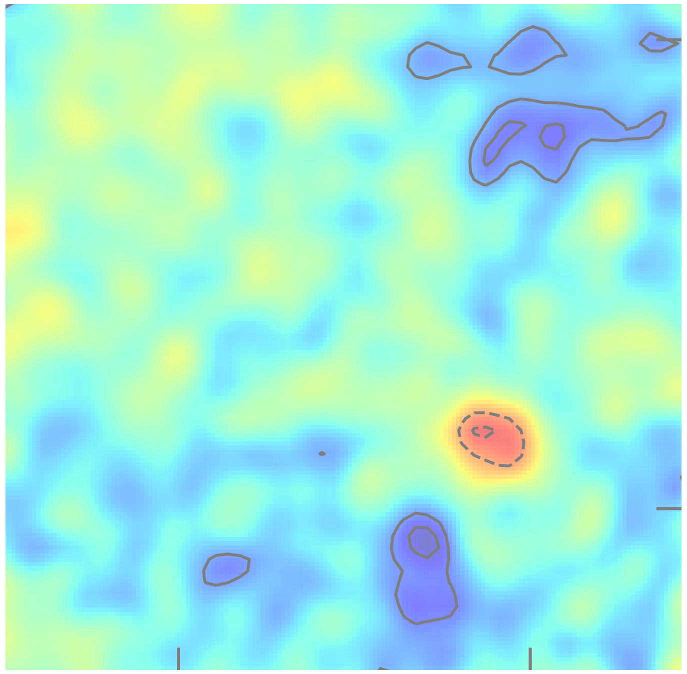
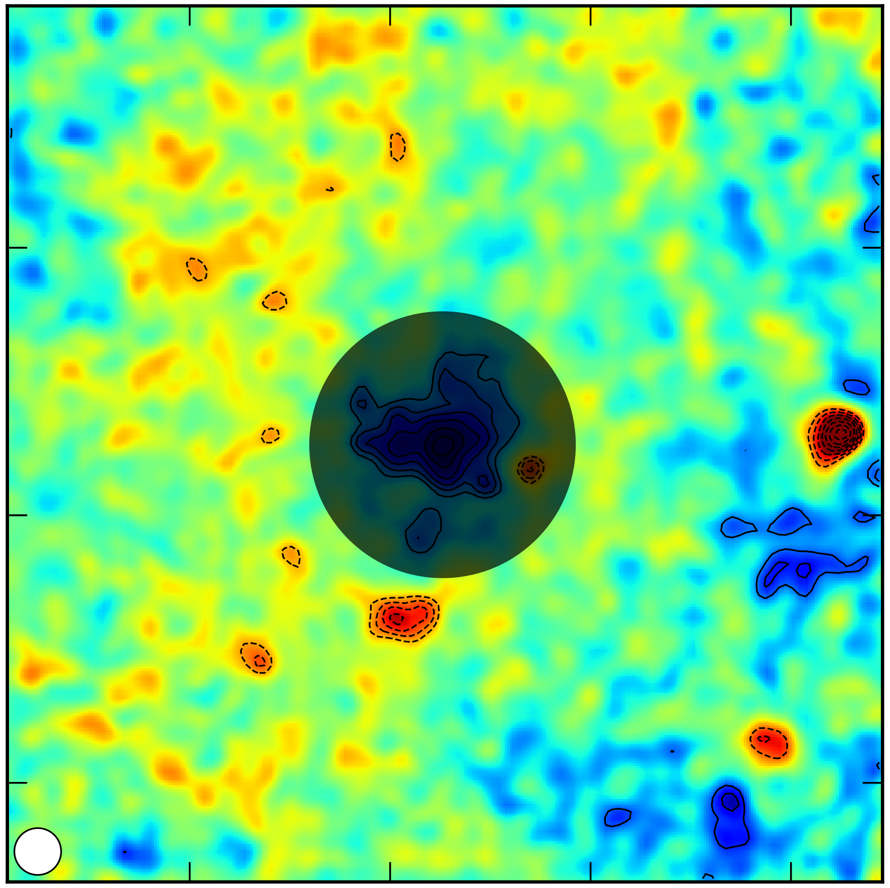


Data reduction : the CMOB method

NIKA2

Decorrelation method used so far : *Common mode one block* (CMOB)

1. Mask out the region of the map containing the signal of interest (*e.g.*, a disk at the center of the map)



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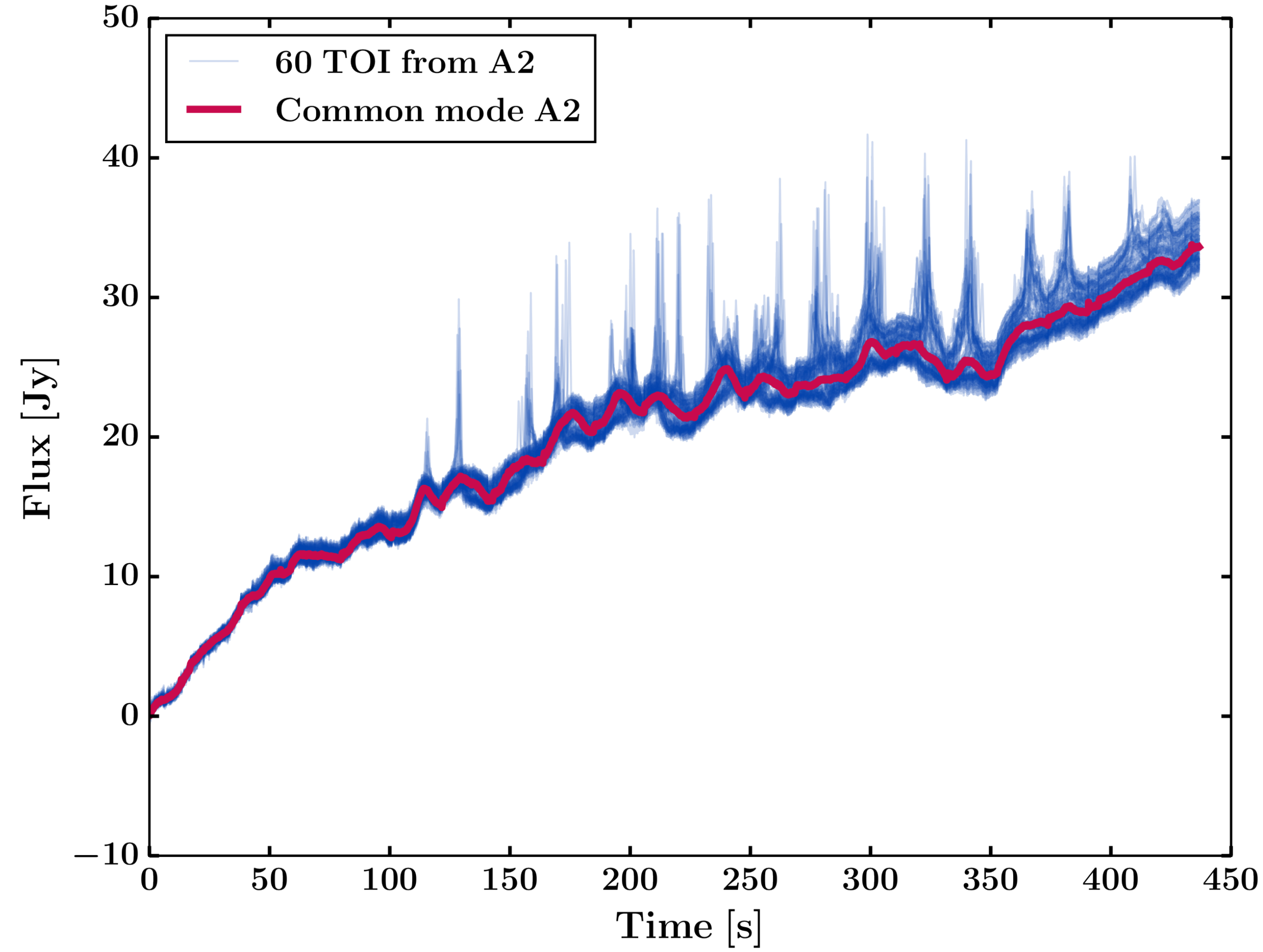
1. Mask out the region of the map containing the signal of interest (*e.g.*, a disk at the center of the map)
2. Compute the medians of TOIs outside of the mask: common mode (CM)



Common mode computation from 60 TOI
(Figure from F. Ruppin)

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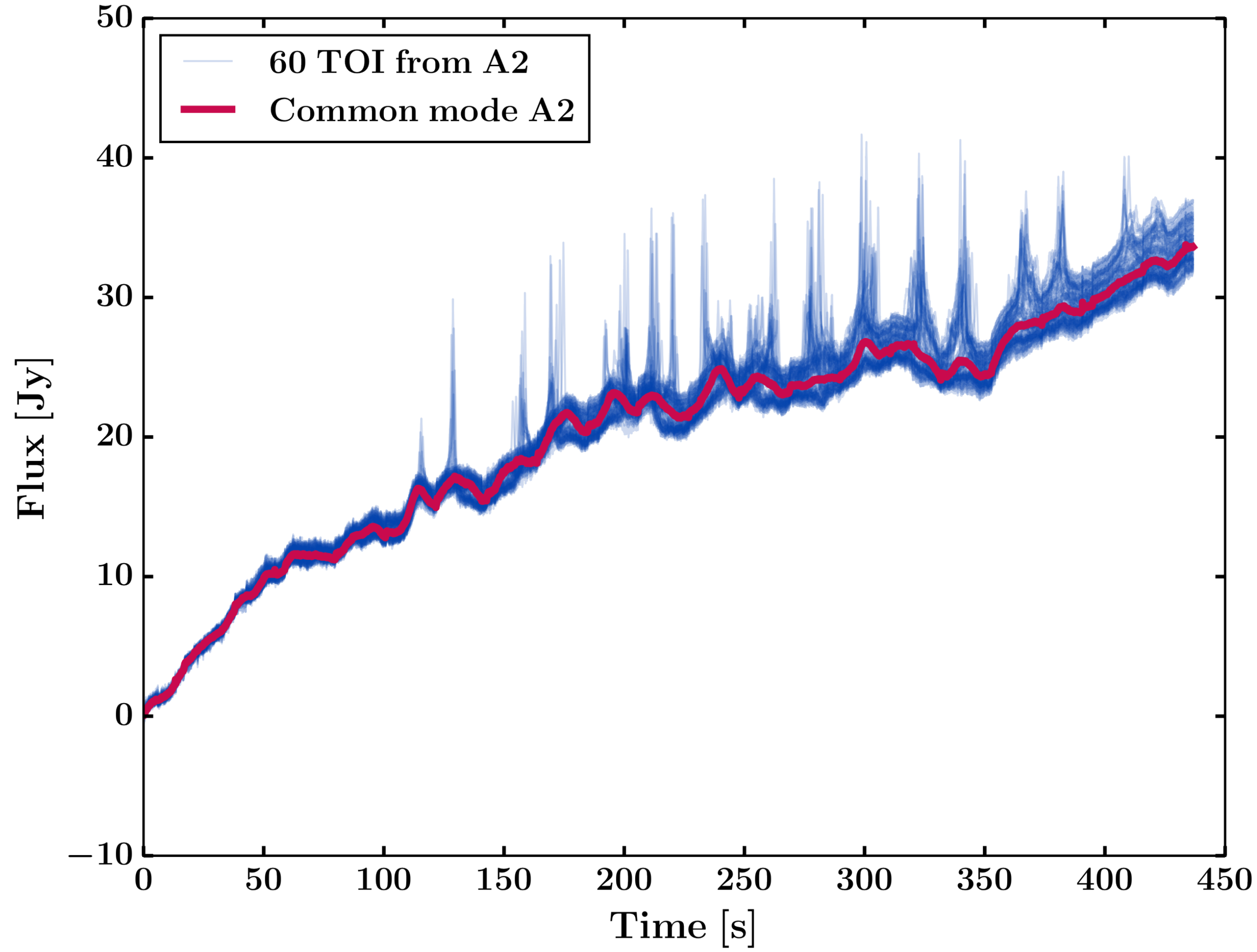
3. Subtract it from all the TOIs, and project them on a map:

Data − CM ≈ Signal + δNoise



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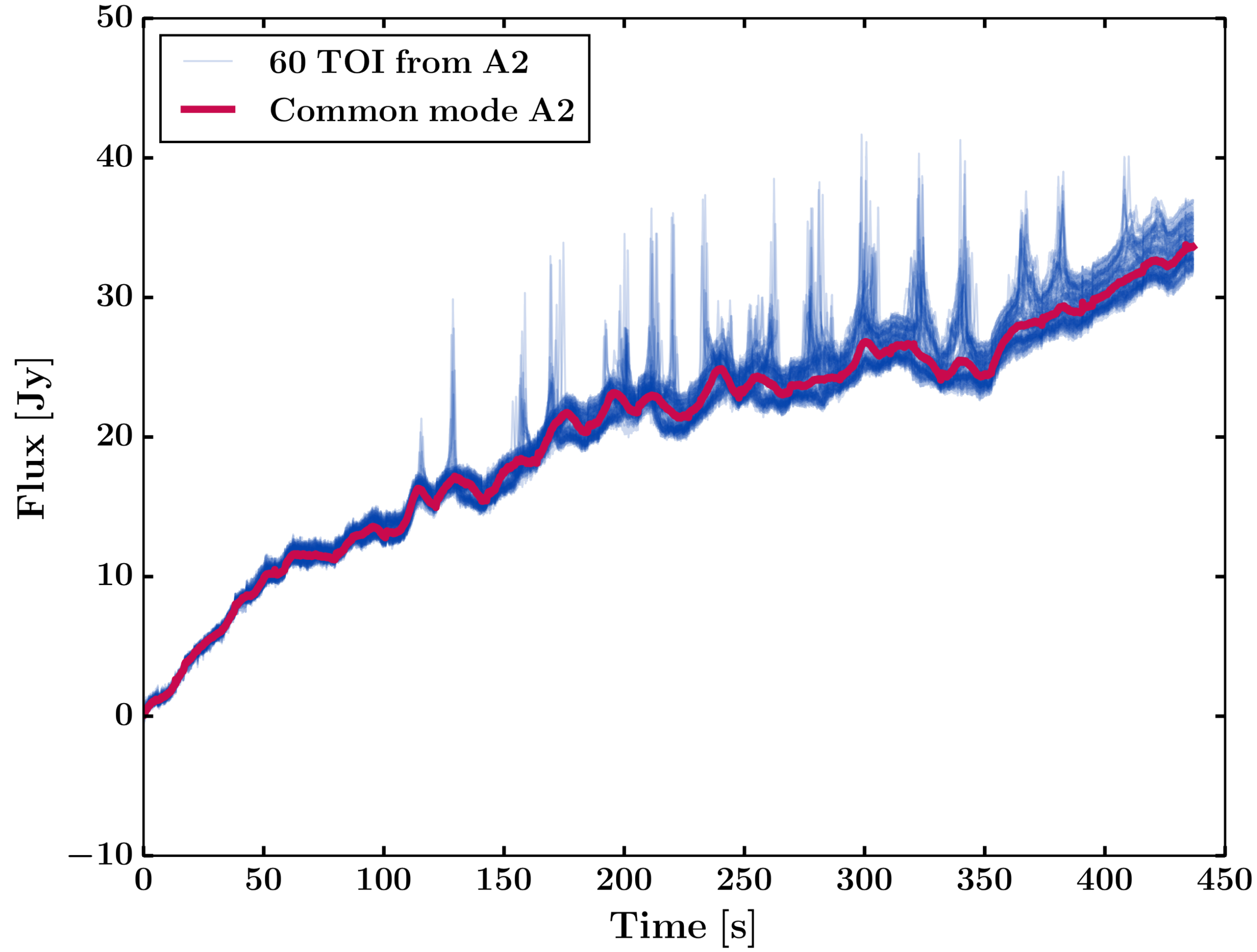
   Data − CM ≈ Signal + δNoise

4. (optional) compute a new mask (*e.g.* where SNR > threshold) and restart

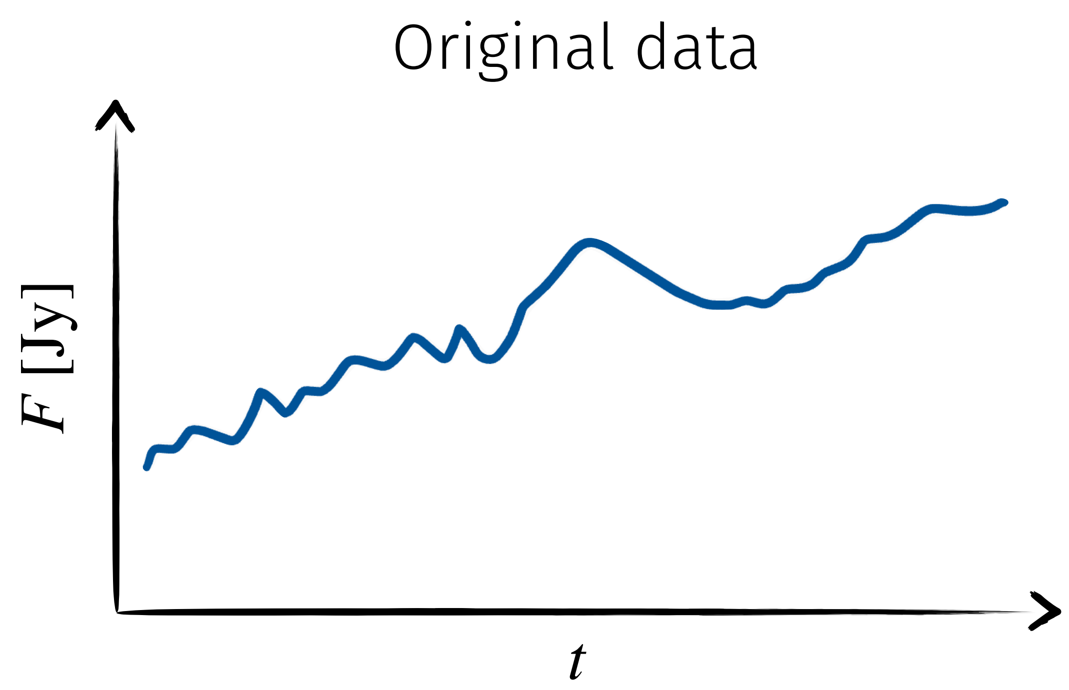


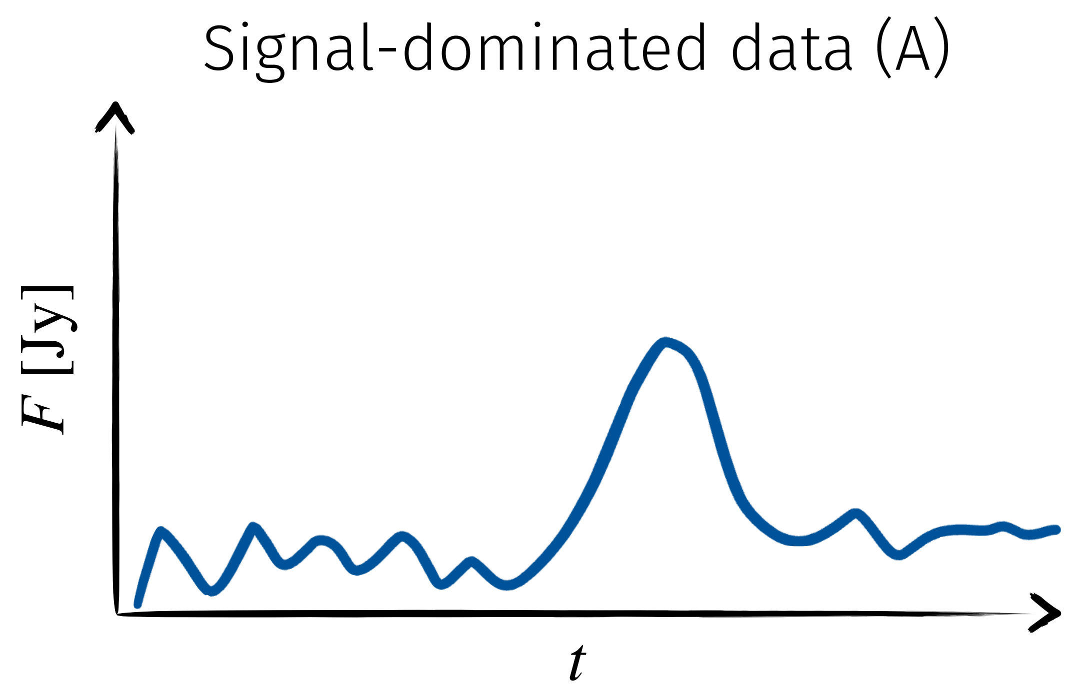
Common mode computation from 60 TOI
(Figure from F. Ruppin)

But… we still have too much noise in the output map

Idea:

1. Get a signal-dominated TOIs (A) using any working decorrelation method



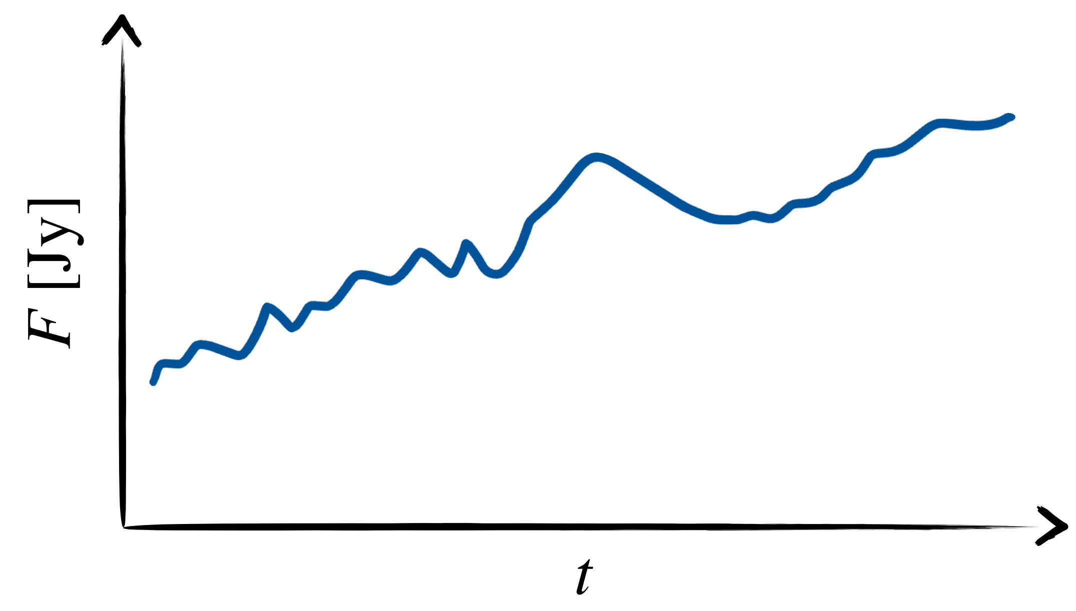


Idea:

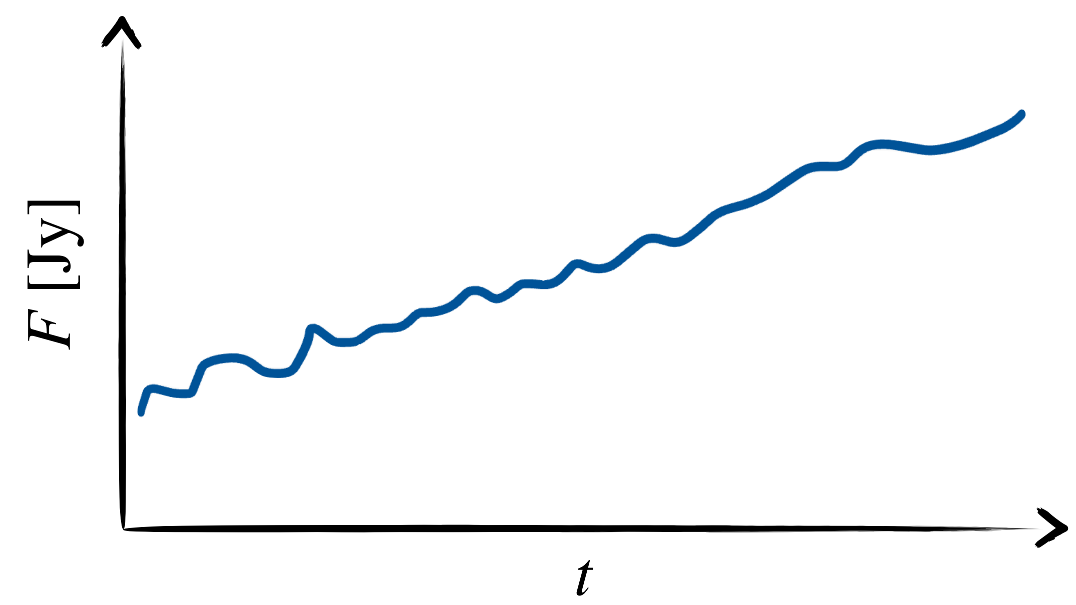
1. Get a signal-dominated TOIs (A) using any working decorrelation method
2. Subtract the signal-dominated TOIs from your data

   → **Only noise remaining (B)**

Original data



Noise only data (B)



Idea:

1. Get a signal-dominated TOIs (A) using any working decorrelation method
2. Subtract the signal-dominated TOIs from your data

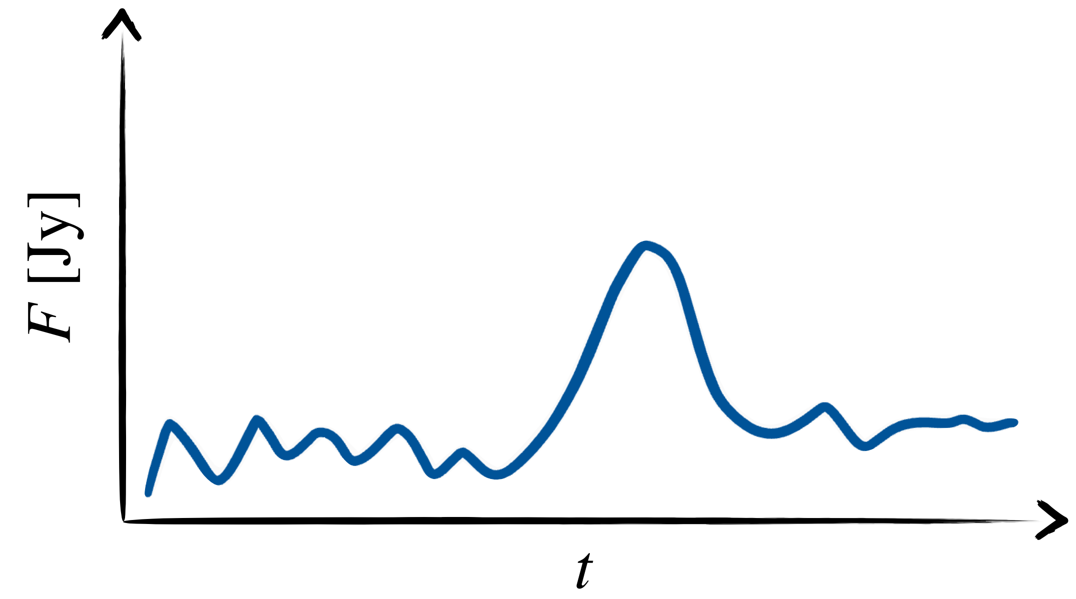
   → **Only noise remaining (B)**

3. Estimate common mode from these “noise TOIs” and subtract it from the original data

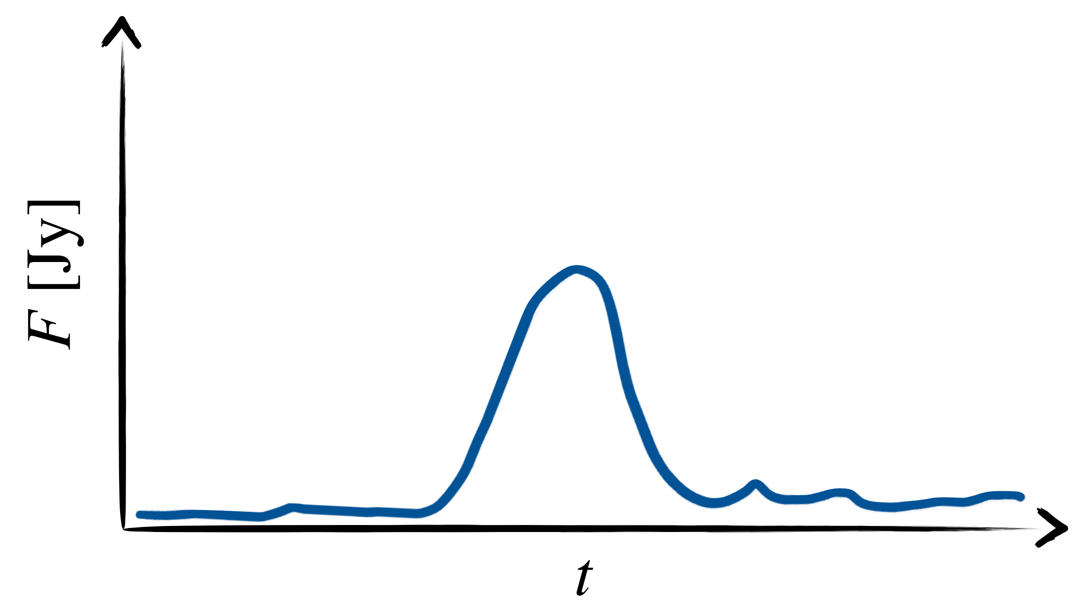
   → **More signal-dominated TOIs (C)**

4. Repeat from step 2 with the new signal-dominated information

Signal-dominated data (A)



More signal-dominated data (C)



Test of another decorrelation

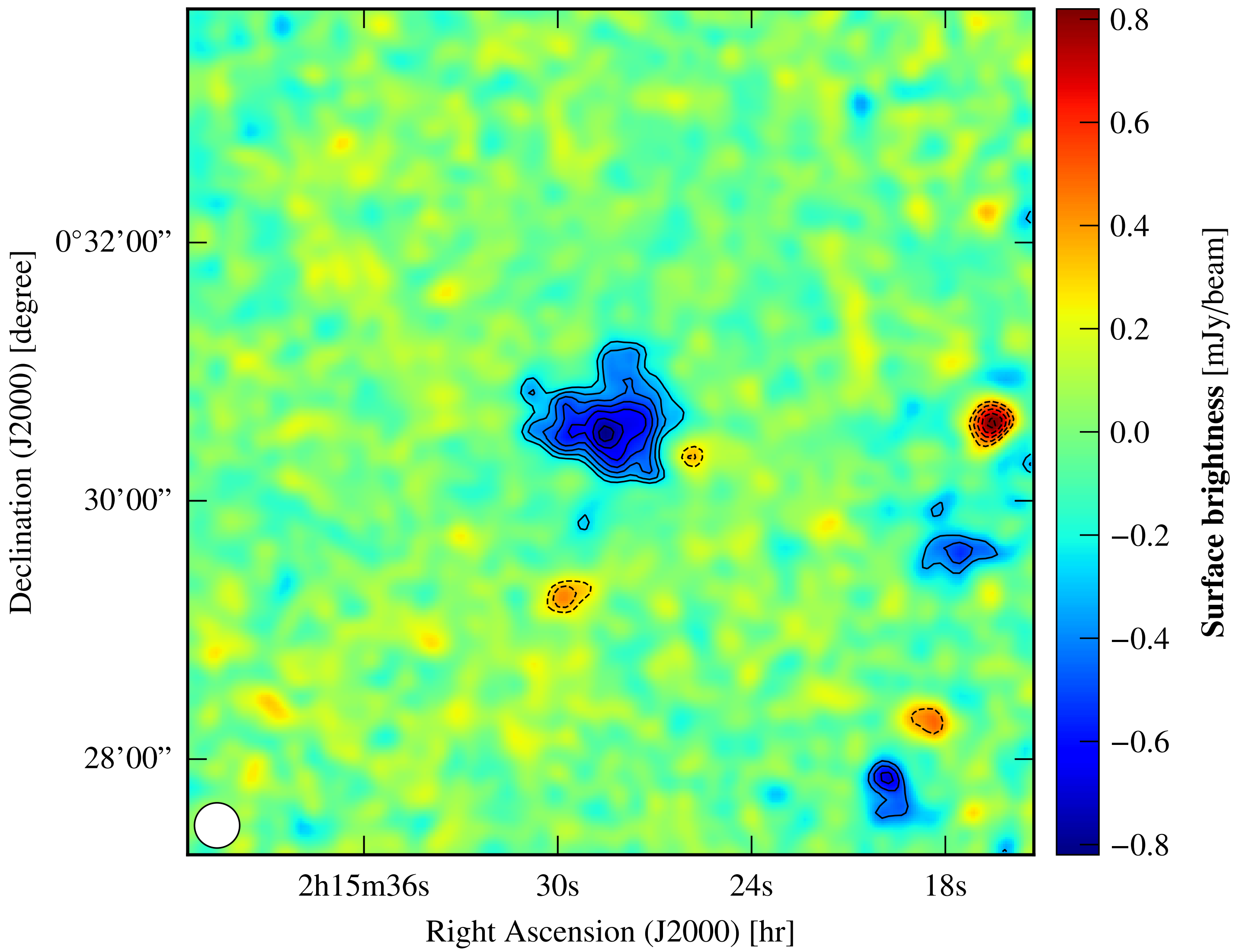
Idea:

1. Get a signal-dominated TOIs (A) using any working decorrelation method
2. Subtract the signal-dominated TOIs from your data

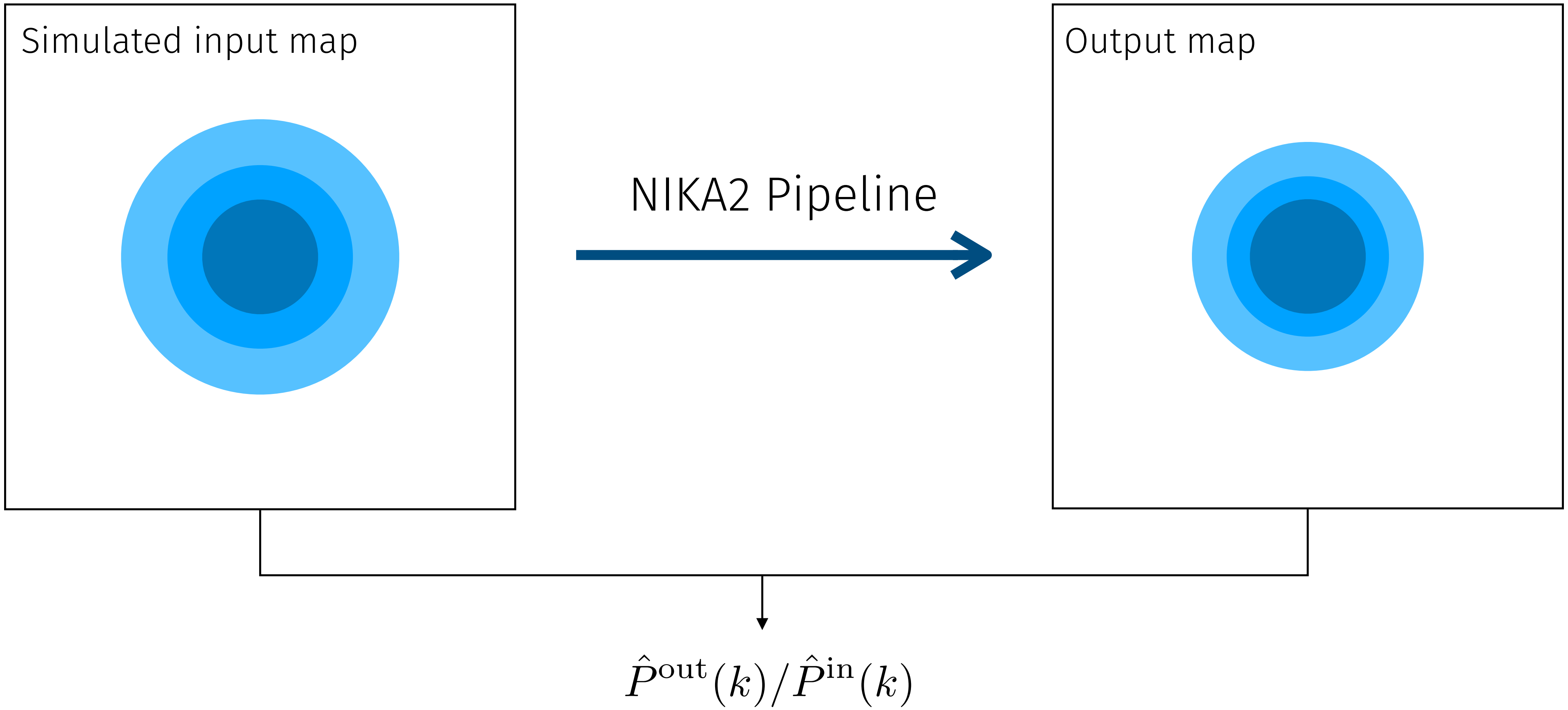
   → **Only noise remaining (B)**
3. Estimate common mode from these "noise TOIs" and subtract it from the original data

   → **More signal-dominated TOIs (C)**
4. Repeat from step 2 with the new signal-dominated information

Result: much better noise removal



Process

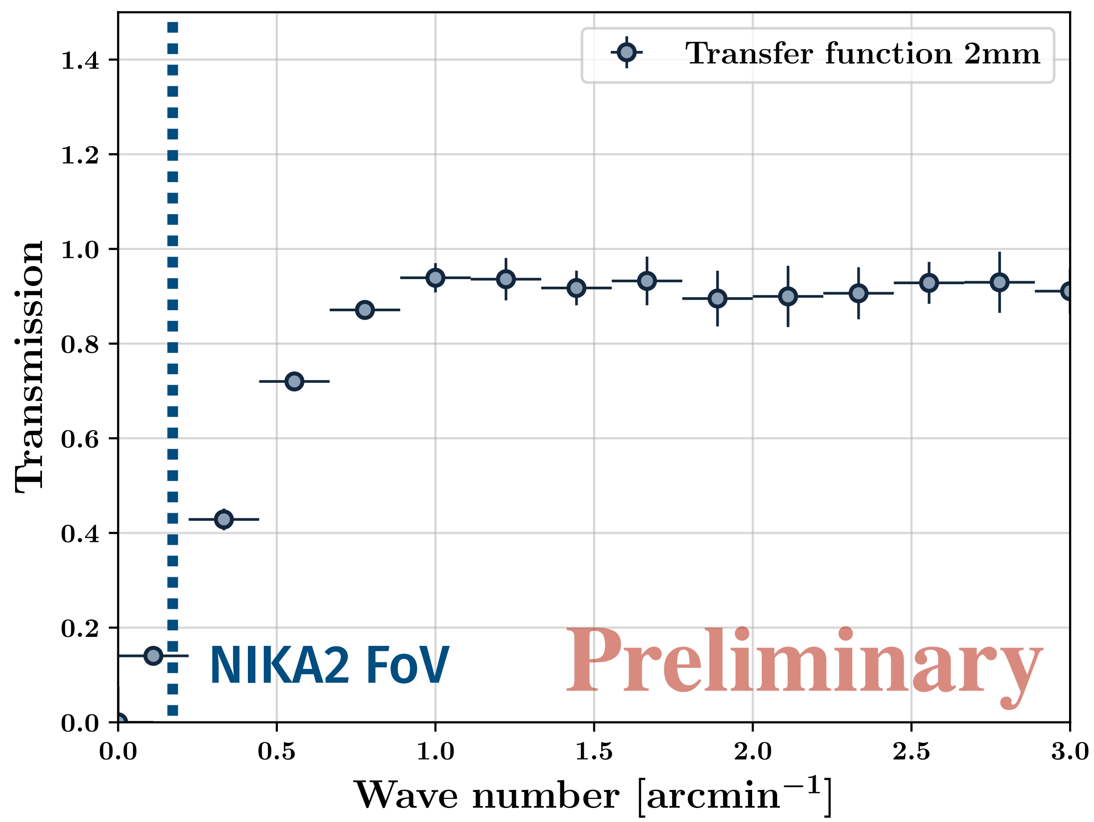


→ Quantifies at which angular scales we lost signal in the analysis ("filtering")

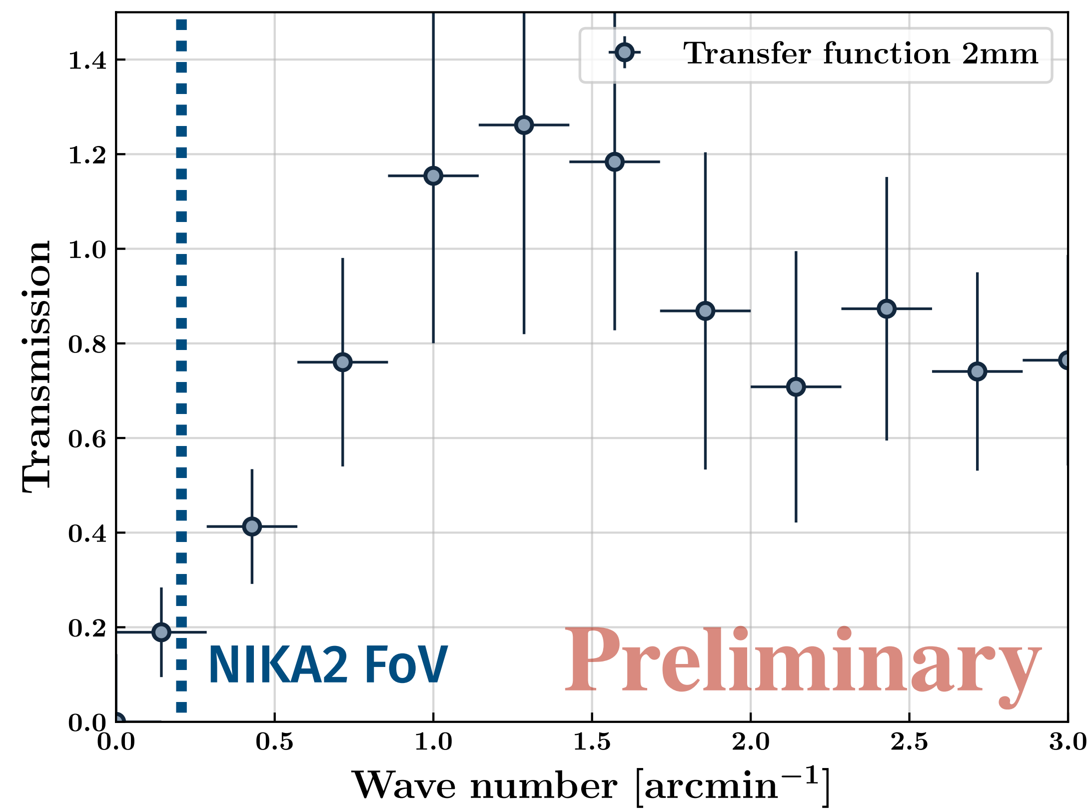
→ Essential tool for SZ model fitting: filtering has to be taken into account when comparing a model to data

Transfer functions comparison

Common Mode One Block:



New method:



We have yet to quantify how much this new method affects our signal :

- Understand transfer function
- See how much point-sources were filtered out

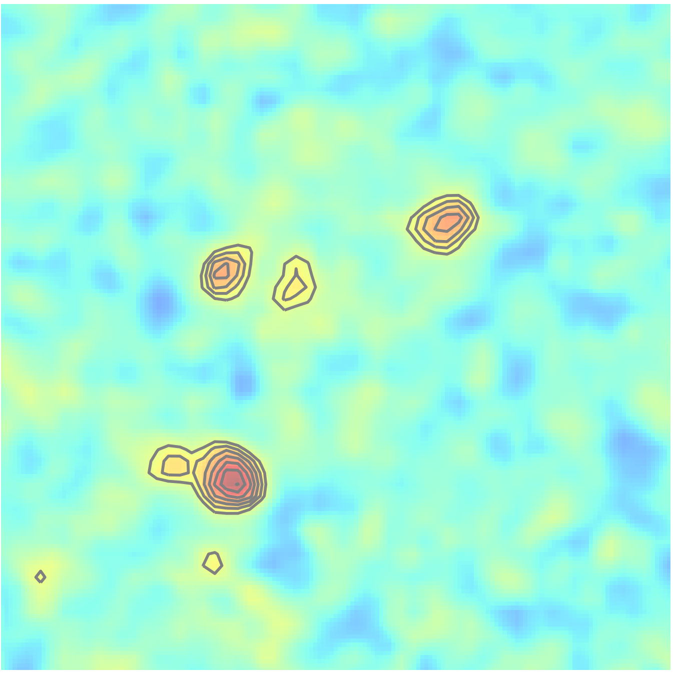
→ The following results are given for the common mode one block method

Introduction & context

Remaining noise in the maps

Point-sources contamination

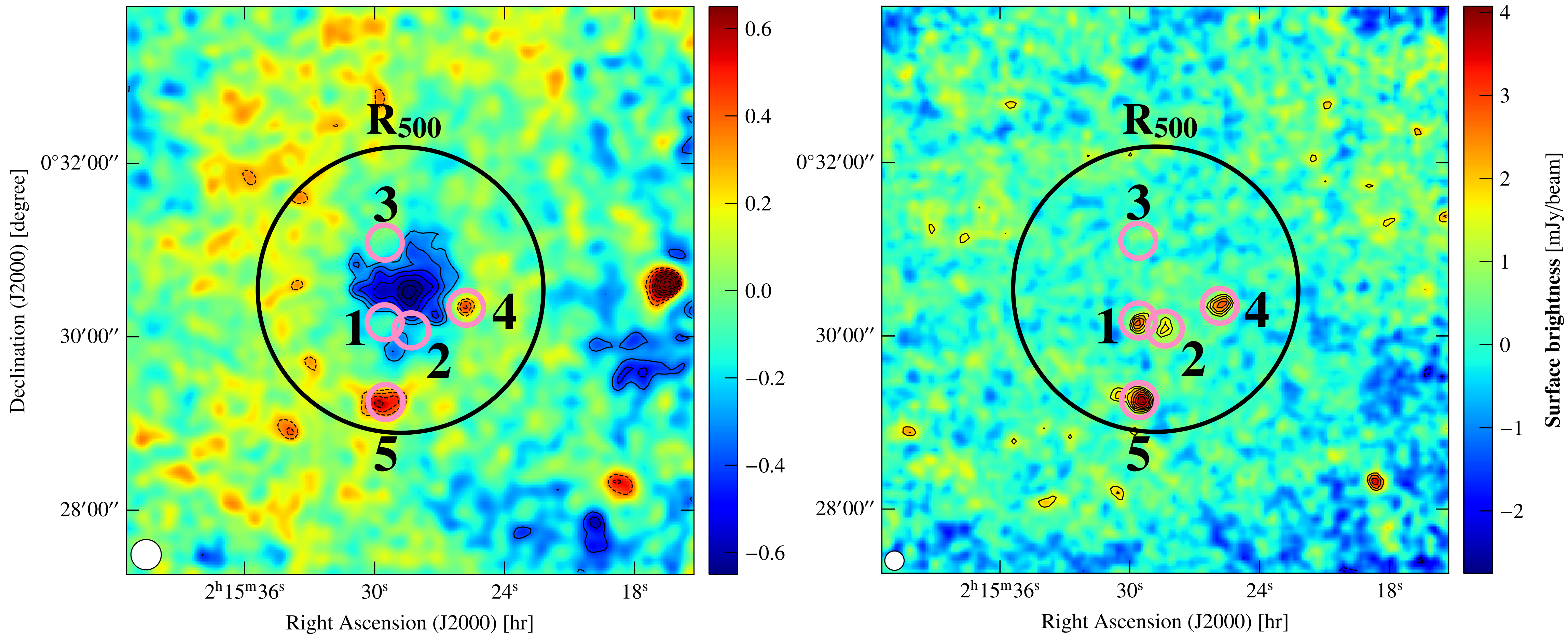
Thermodynamics of the ICM



Sub-millimetric sources in the field

NIKA2

Identification of 5 sub-mm sources (○) near the cluster from HerS82 catalog (Viero et al. 2014)



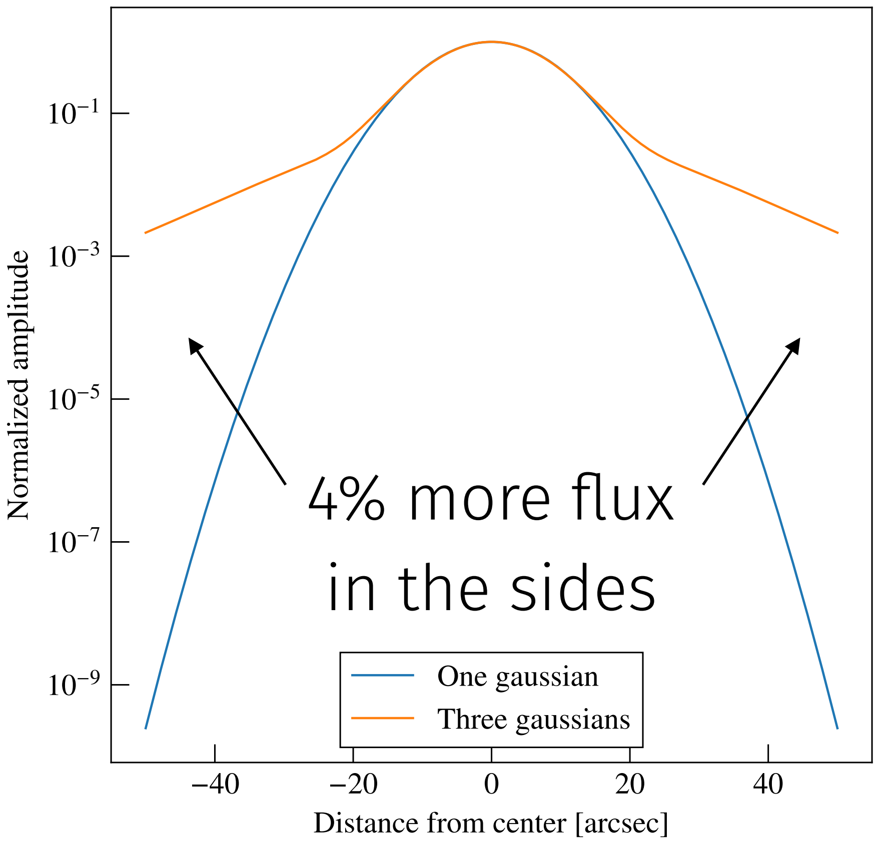
- For each identified source, we have Herschel SPIRE fluxes (at 250, 350 and 500 μm)
- Sources close to the cluster (within R_{500})
  → estimating contamination is important
- Small cluster (area ~ a few beams)
  → need a precise knowledge of the sources' extension

Point-source removal: Example of source #4 (1/2)

Fit point sources in the NIKA2 1mm map as a NIKA2 beam profile: *sum of 3 gaussians*

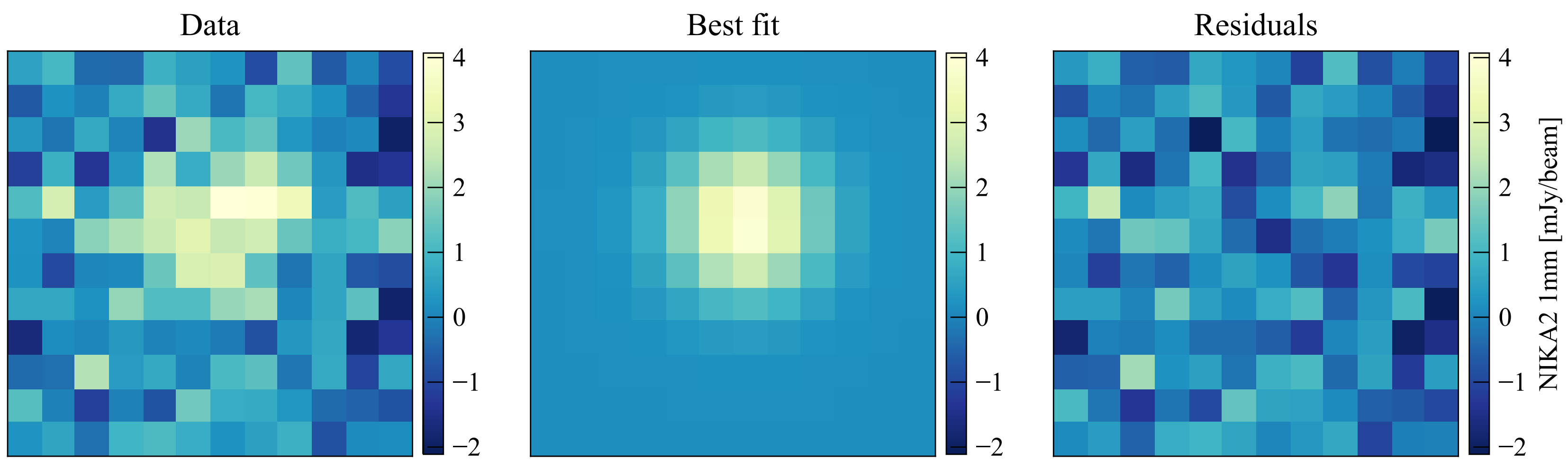
(Perotto *et al.* 2019, in prep)

- Better modeling of the beam than simple gaussian profile
- More flux in the sides of the profile
  → Better point-source removal



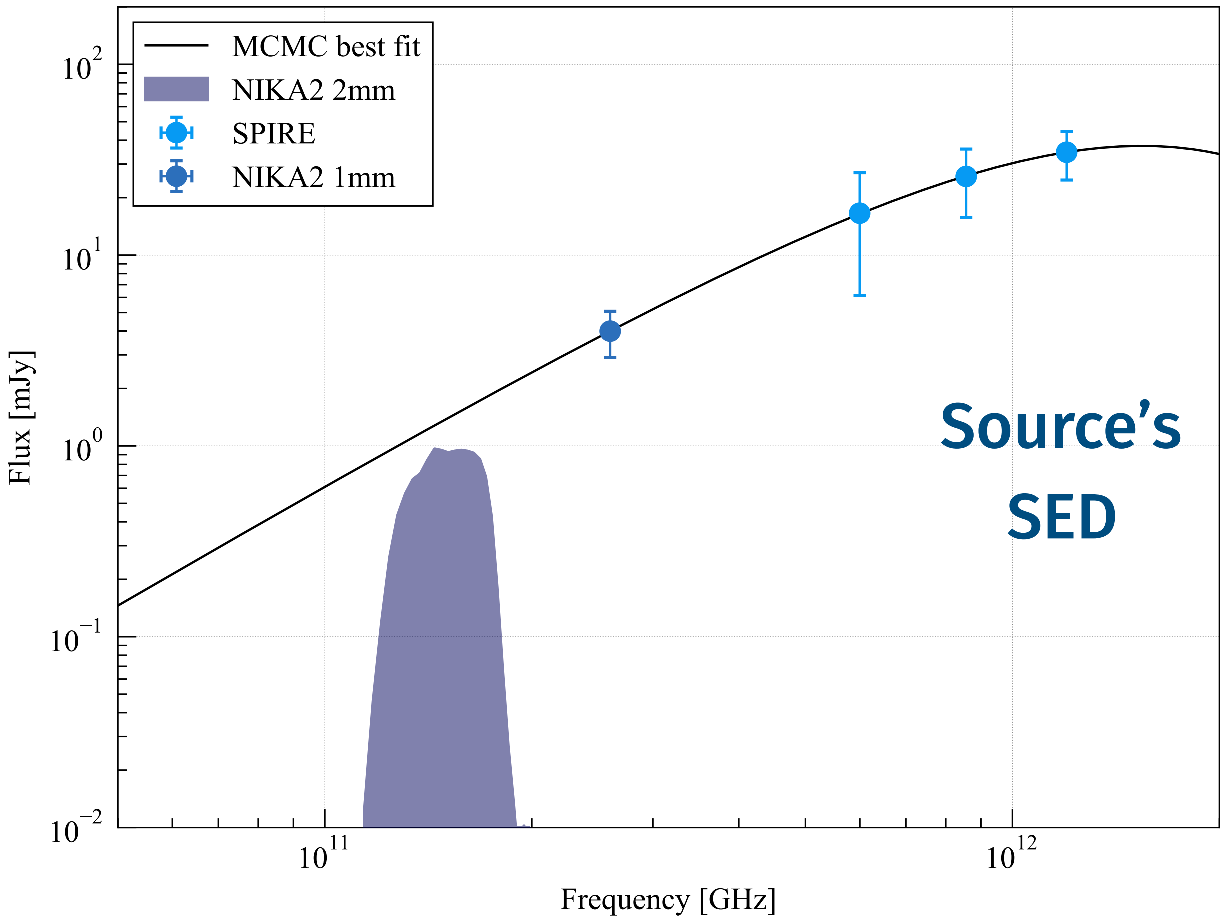
amplitude = flux of the source at 1mm

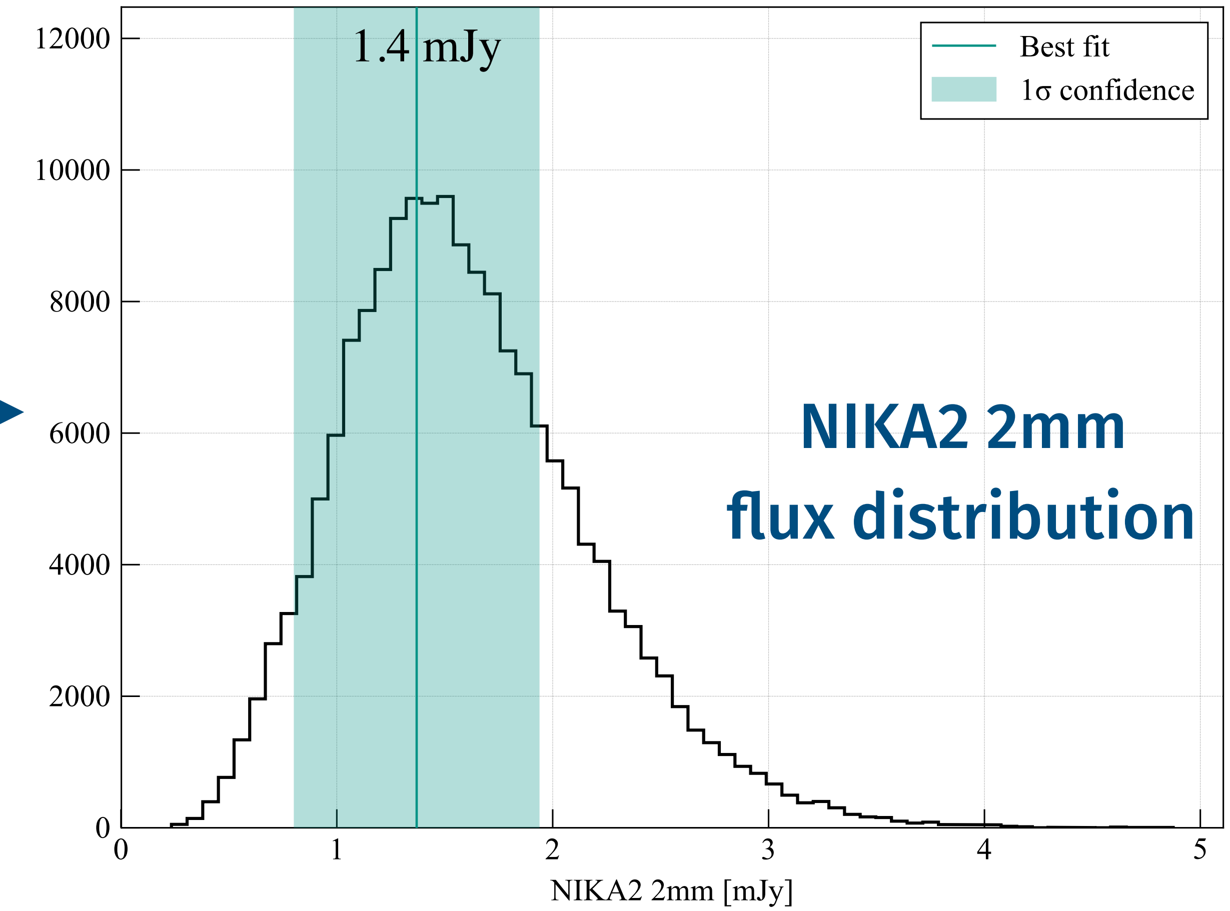
Extraction result :



→ We have the flux of the source in **4 frequencies**, and we can fit its **SED**

We use MCMC to fit the SED, and integrating the SEDs from the posterior distribution in the NIKA2 2mm bandpass gives us the 2mm flux distribution



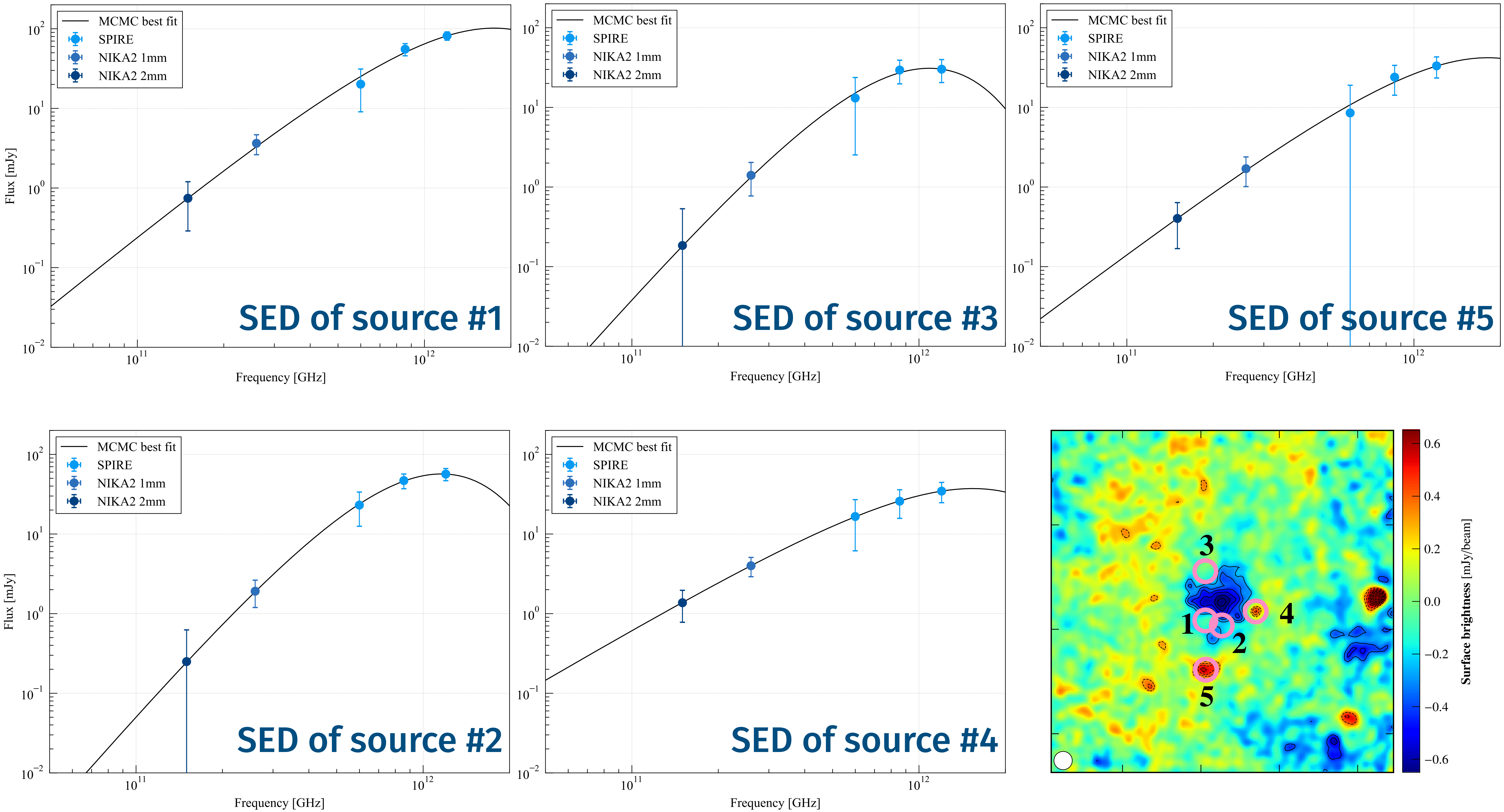


2 ways to use this:

1. Get one value of 2mm flux, and subtract it from the 2mm map
2. Use the PDF as prior in MCMC fit of (SZ profile + point-sources)
   → To be done

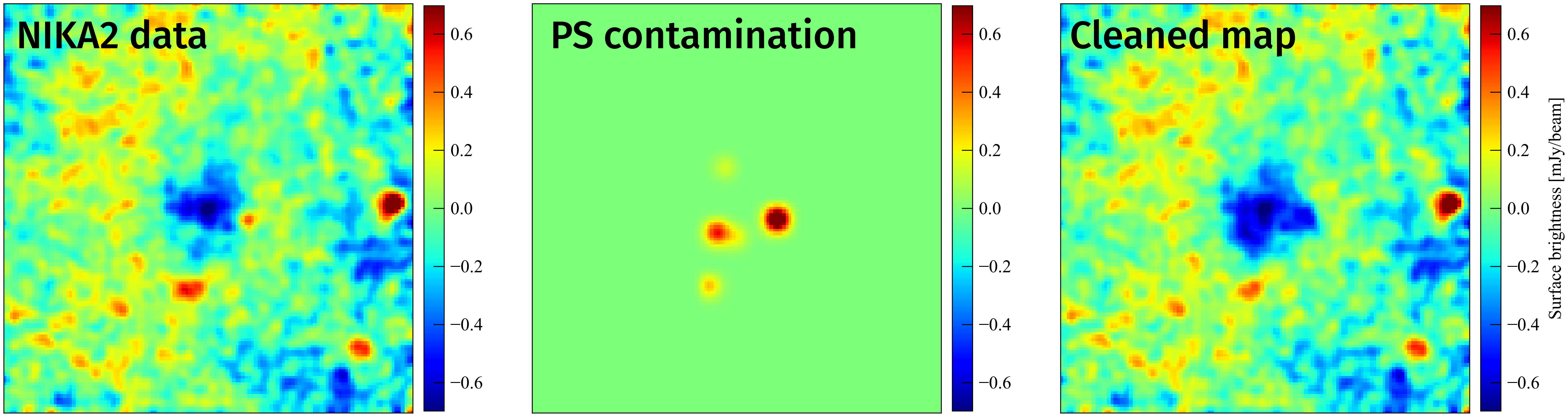
SEDs of all sources

NIKA2



Point-source removal results

Applying to all 5 sources, we get their 2mm fluxes; modelling them as a NIKA2 beam profile, we can remove them from the 2mm map:



In some regions, point-source flux > SZ signal

→ Correction accuracy is essential for model fitting

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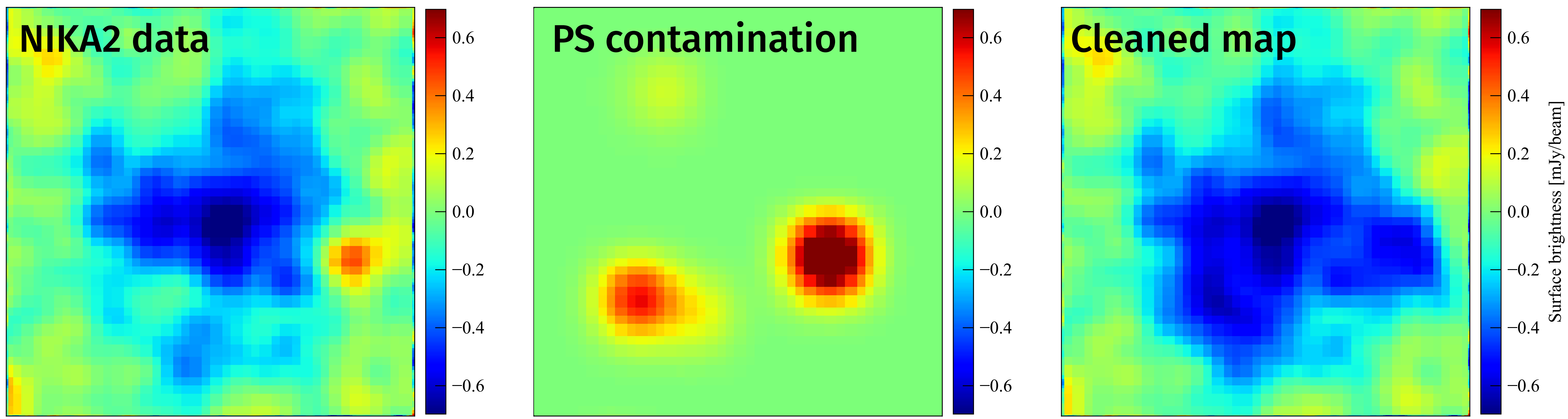

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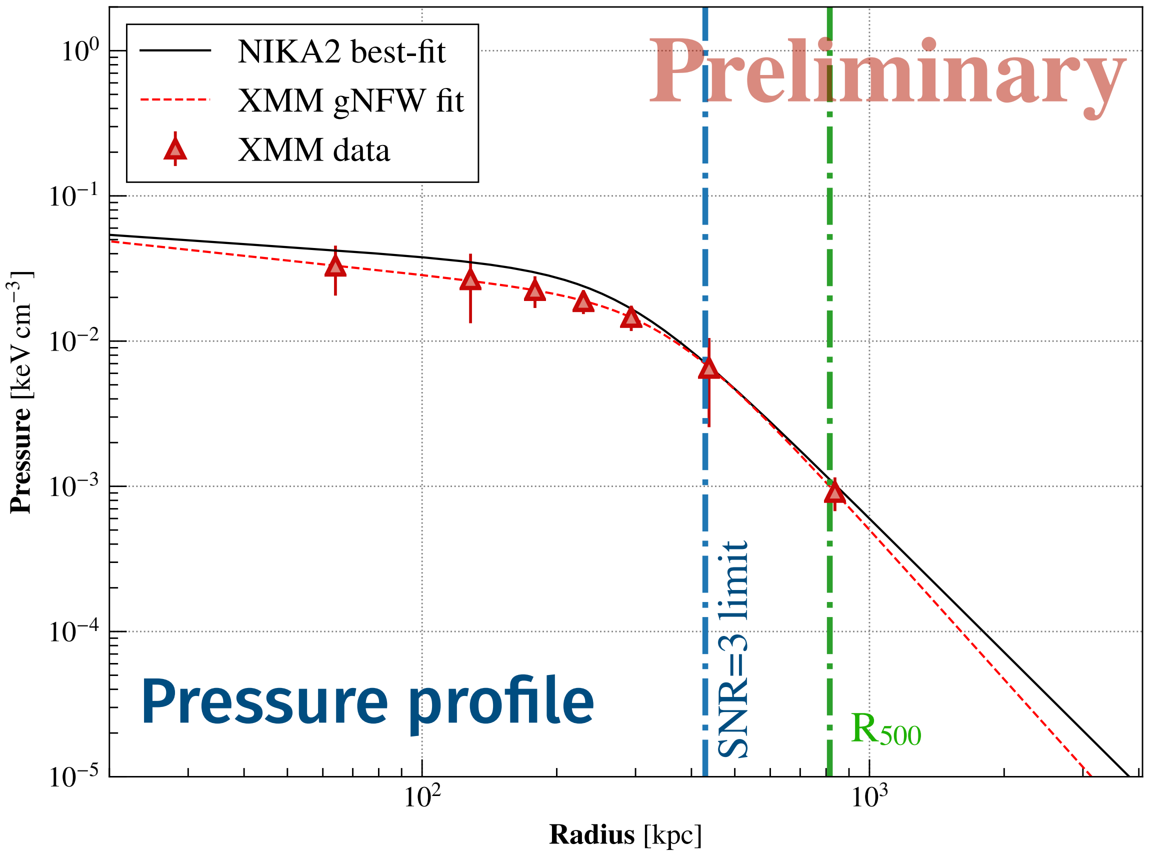
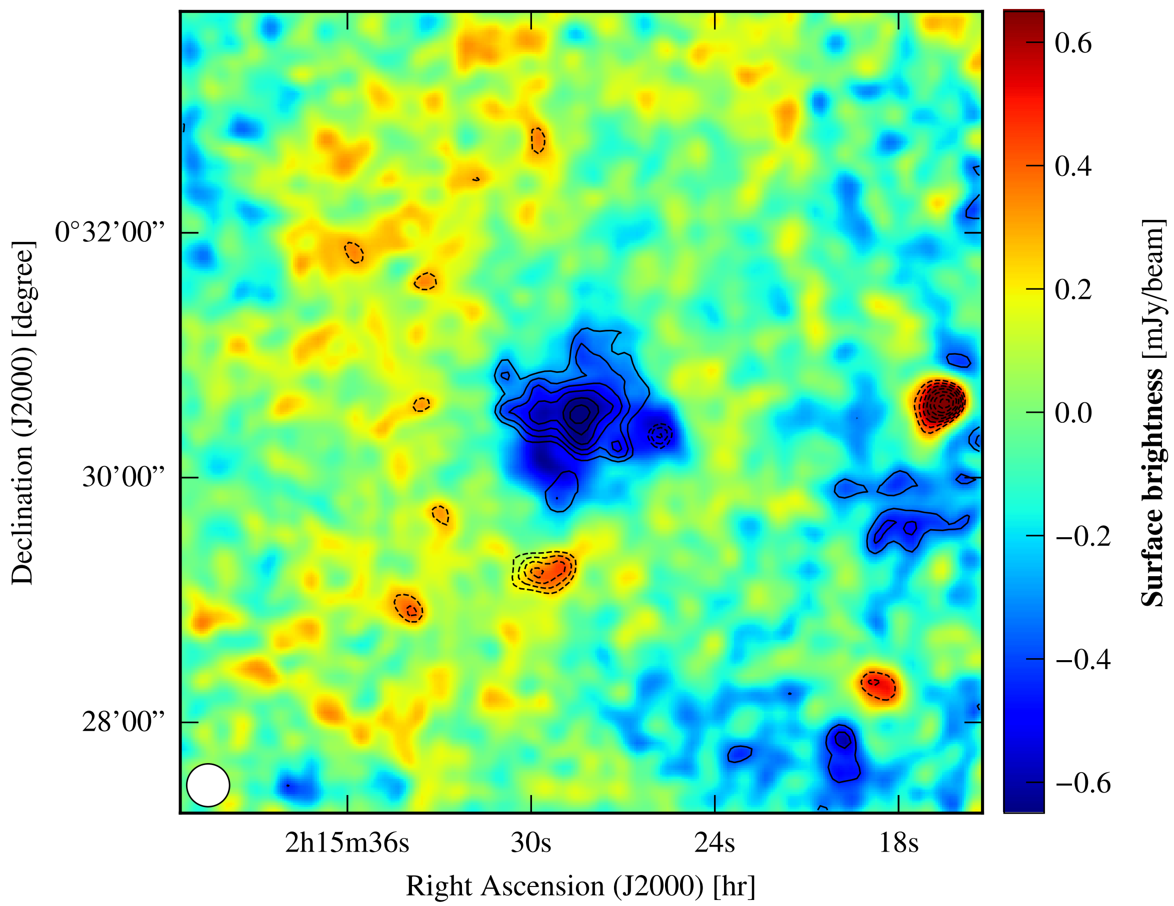
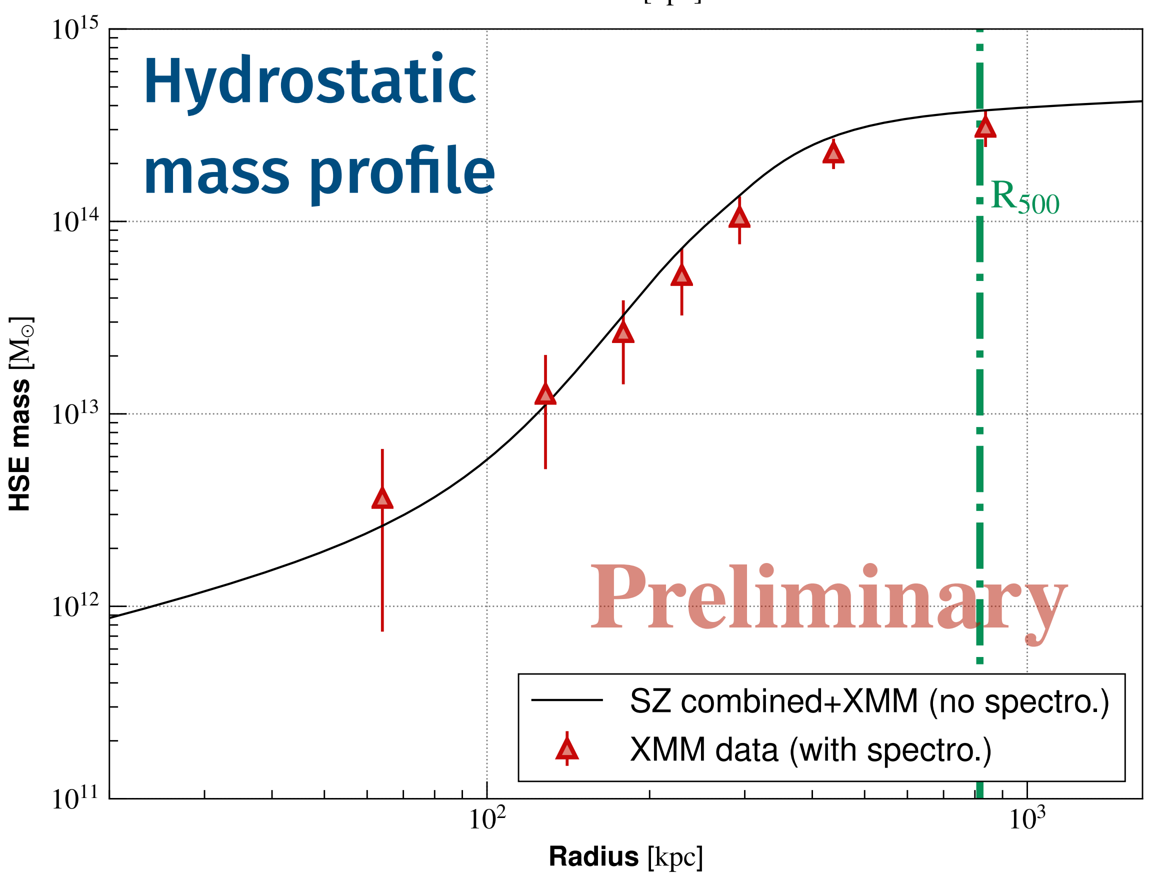
Outline







- Good agreement between XMM (with spectra) and NIKA2
- Computation of the cluster mass from our profiles:

$$M_{500} = (3.86 \pm 0.42) \times 10^{14}\, M_\odot$$

Prior knowledge (ACT + scaling relation):

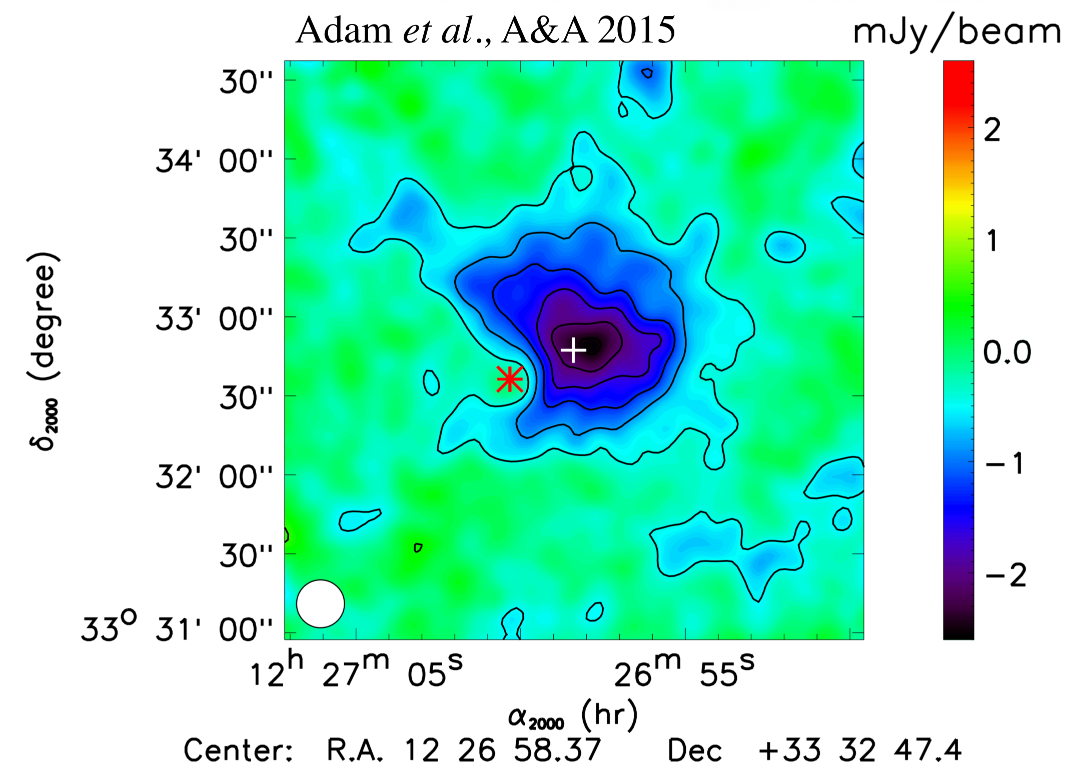
$$M_{500} = (3.79 \pm 0.59) \times 10^{14}\, M_\odot$$

Comparison with NIKA

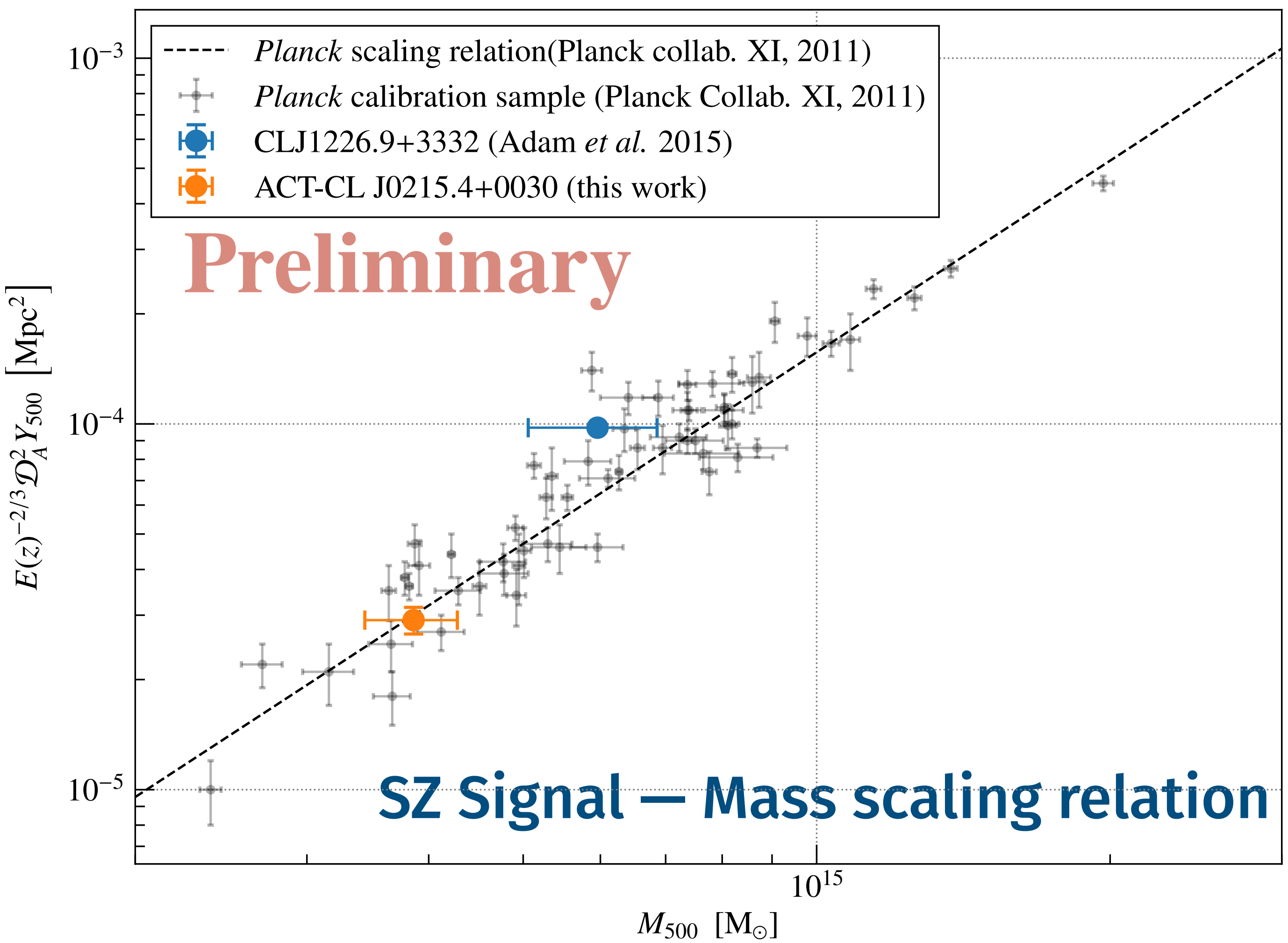
NIKA2

CLJ1226.9+3332: High redshift cluster observed by NIKA (Adam *et al.*, A&A 2015, Romero *et al.*, A&A 2018)

- Redshift similar to ACT-CL J0215.4+0030
- Higher mass
- Similar results (good agreement with XMM data after point-sources subtraction)



Cluster	z	M_{500} $[10^{14} \mathrm{M}_\odot]$
CLJ1226.9+3332	0.89	$5.96^{+1.02}_{-0.79}$
ACT-CL J0215.4+0030	0.87	3.86 ± 0.42



SZ Signal — Mass scaling relation

→ NIKA2 gets results comparable to NIKA for much lighter clusters

What if we hadn't removed point-sources?

NIKA2

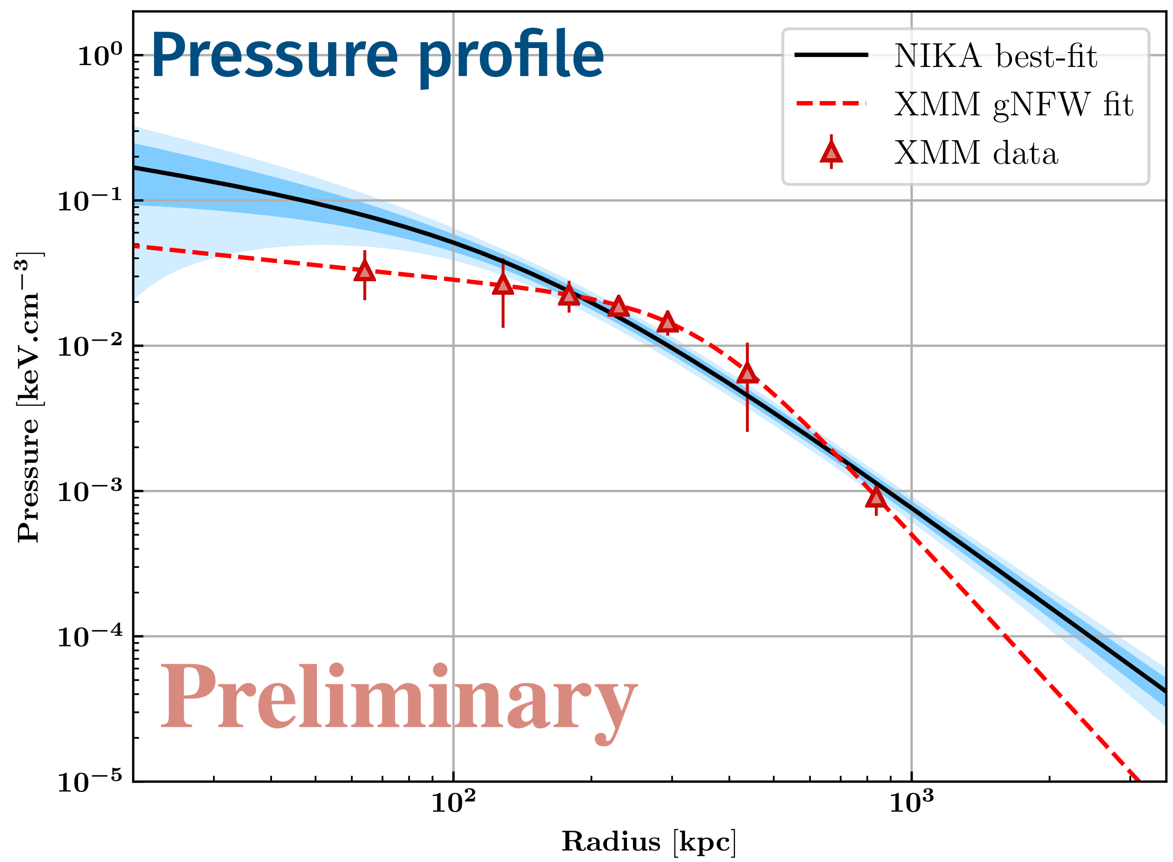
⚠ Not point-sources corrected ⚠

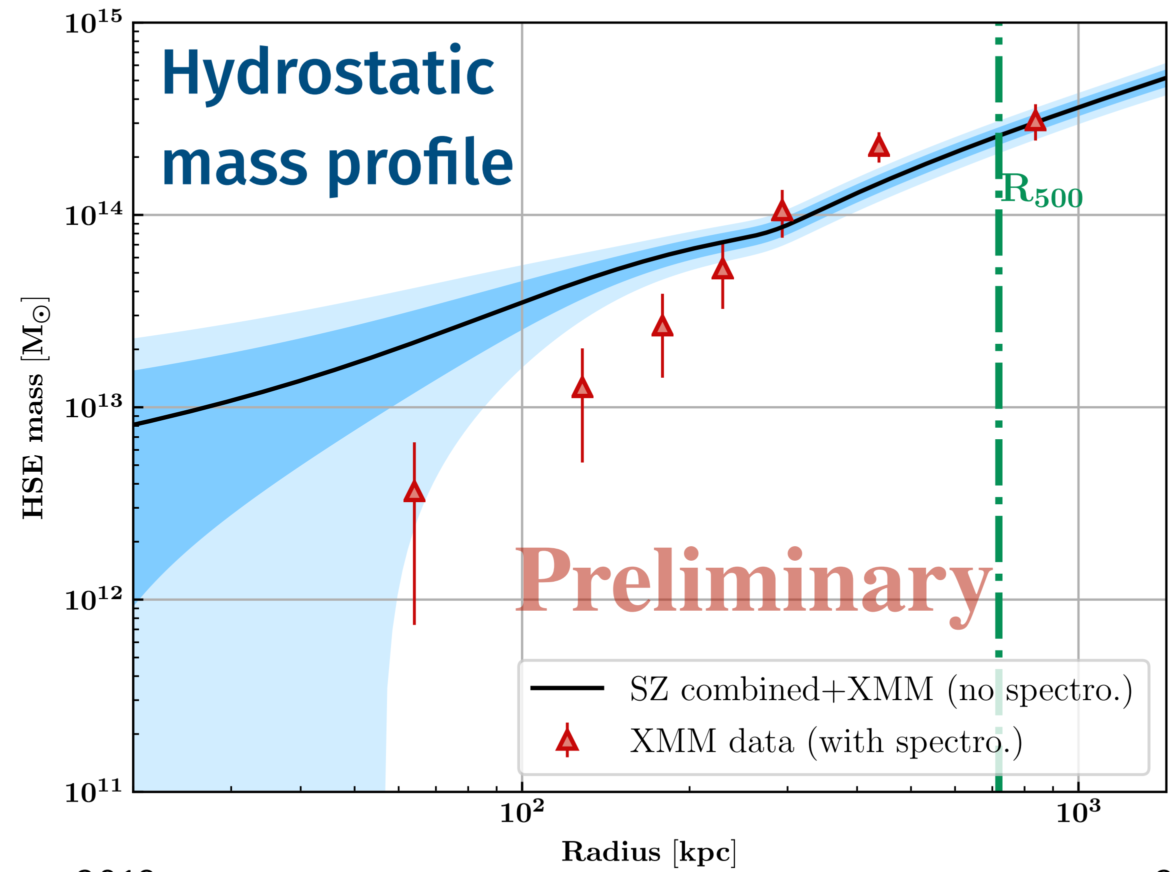
Large disagreement between XMM and NIKA2 data:

- Bad point-source removal will give poor profiles quality

  → **We need to remove them correctly**

- What if we didn't have information on the sources ?
  - **21/48** LPSZ clusters have no *Herschel* information





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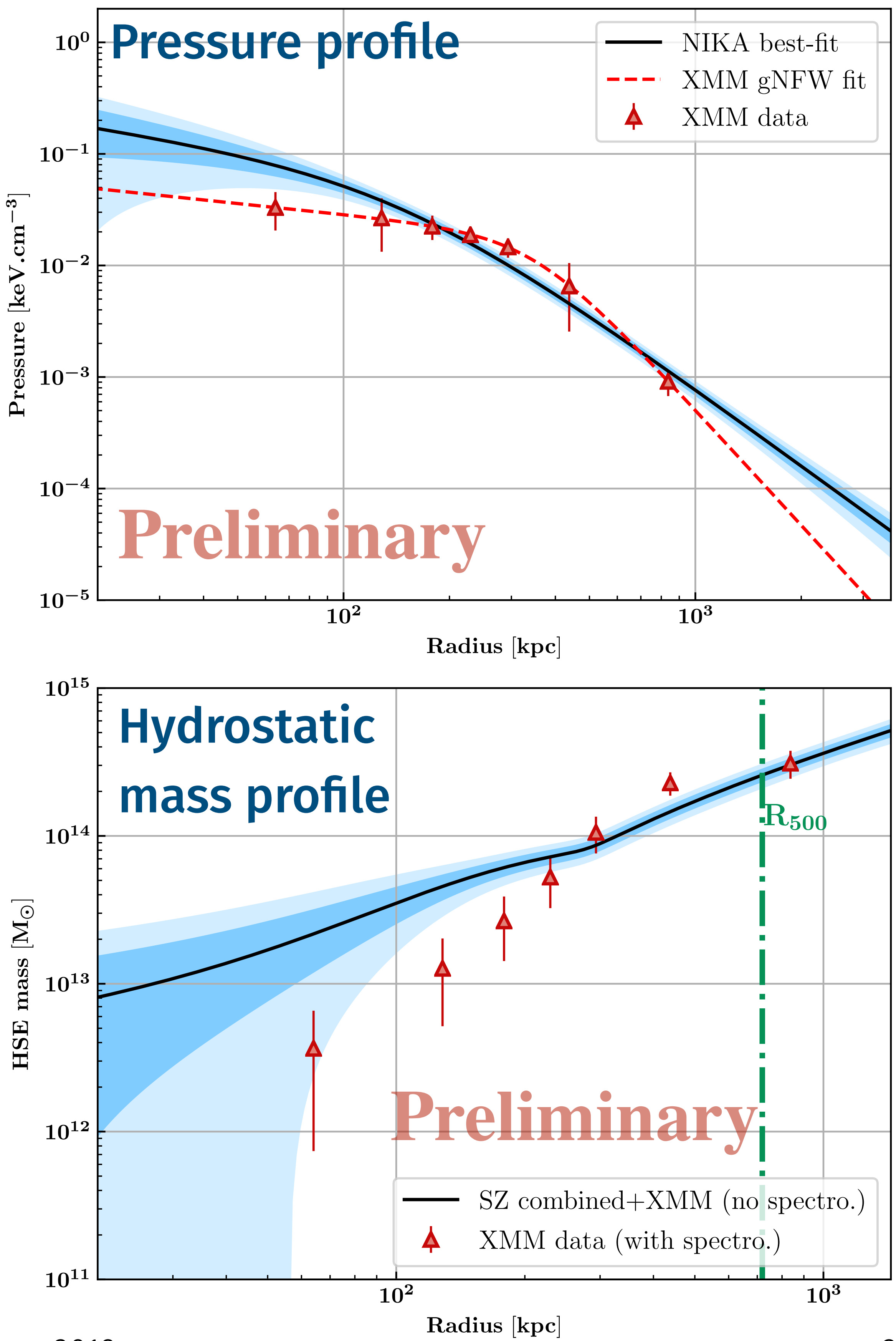
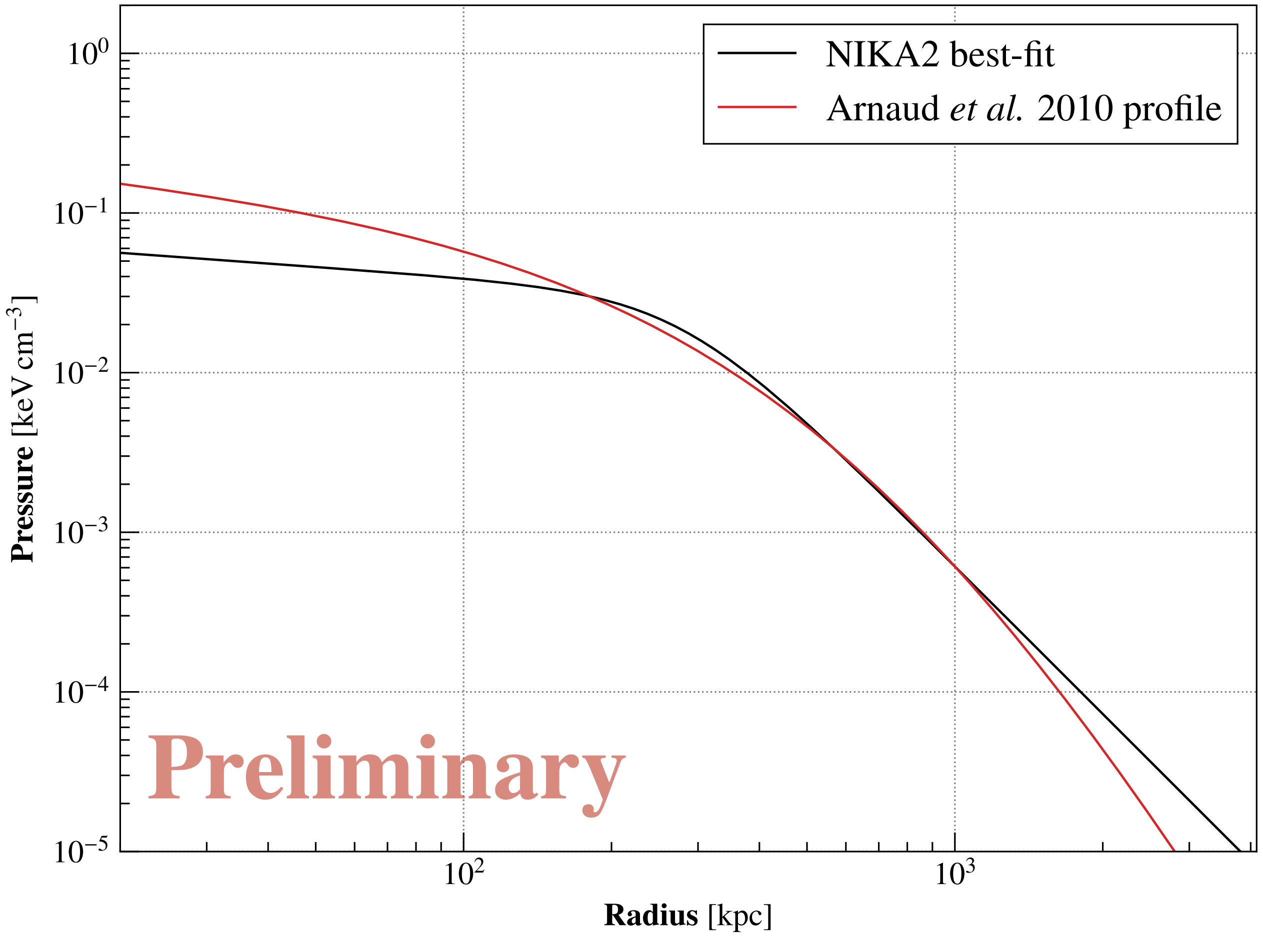
→ What will be the impact of undetected sources on our analysis?



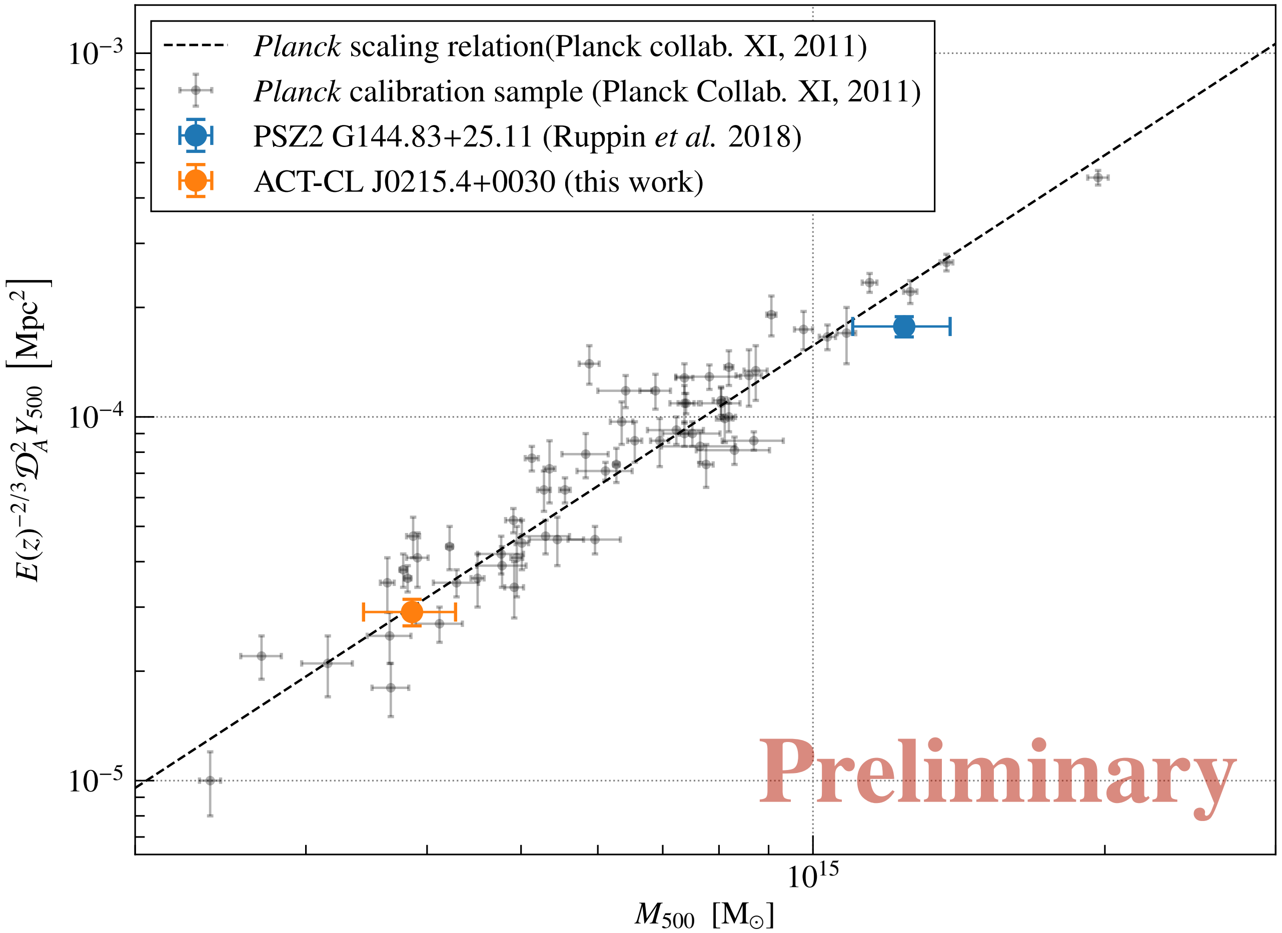
LPSZ products

Pressure profile



Significant deviation from Arnaud *et al.* 2010 universal pressure profile

Scaling relation



So far, agreement with the Planck scaling relation (on two clusters)

No conclusion can be drawn from 2 clusters → have to wait for the full LPSZ sample

Conclusions & perspectives

- Great synergy between NIKA2 data and XMM-*Newton* imaging data at low SNR

→ **Encouraging for future analysis of clusters with no X spectroscopy**

- Decorrelation process is still in development, along with careful study of the filtering and transfer function

- Information on point-source contamination is **crucial** for LPSZ analysis, as bad point-source removal will lead to bad ICM reconstruction

→ **Systematic effects of undetected sources on the pressure profile need to be investigated**

The results presented here reflect a collective effort from the members of the NIKA2 LPSZ team

LPSC Grenoble

Florian KERUZORE
Juan MACIAS-PEREZ
Frederic MAYET
Laurence PEROTTO

CEA

Monique ARNAUD
Hervé AUSSEL
Iacopo BARTALUCCI
Jean-Baptiste MELIN
Gabriel PRATT

IRAP

Nicolas CLERC
Etienne POINTECOUTEAU

MIT

Florian RUPPIN

Sapienza Università di Roma

Marco DE PETRIS

Instituto de Astrofísica de Canarias

Rafael BARRENA DELGADO
Antonio FERRAGAMO
Jose Alberto RUBINO MARTIN

IPAG

François-Xavier DESERT
Nicolas PONTHIEU

Charles ROMERO

Rémi ADAM

IAS Orsay

Nabila AGHANIM
Marian DOUSPIS

LAM

Alexandre BEELEN

Chiara FERRARI

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