Joint contraints on the galaxy cluster pressure profile from Planck and SPT-SZ

Jean-Baptiste Melin,
Gabriel W. Pratt, Monique Arnaud
CEA Paris-Saclay

Observing the millimeter Universe with the NIKA2 camera (June 28 – July 2, 2021)
Motivations

• Only one published study on cluster profiles using the SPT-SZ data (*Plagge et al. 2010*, 15 clusters)
• No statistical SZ profile study based on a large number (hundreds) of clusters

• Both SPT-SZ and Planck data now publicly available (*)
• Excellent complementarity of the two datasets
• **Combining** the two datasets allows for *reconstructing better the inner and outer parts of the average cluster profile*

• Combination ACT+Planck (*E. Pointecouteau*, 31 clusters)
• Combination SPT-SZ+Planck (*F. Oppizzi*, individual clusters)

(*) SPT-SZ [https://lambda.gsfc.nasa.gov/product/spt/spt_prod_table.cfm](https://lambda.gsfc.nasa.gov/product/spt/spt_prod_table.cfm)
Planck [https://pla.esac.esa.int/#home](https://pla.esac.esa.int/#home)
### SPT-SZ and Planck complementarity

<table>
<thead>
<tr>
<th></th>
<th>SPT</th>
<th>Planck</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial resolution</strong></td>
<td><img src="image.png" alt="+" /> (fwhm=1.75arcmin)</td>
<td><img src="image.png" alt="−" /> (fwhm&gt;5arcmin)</td>
</tr>
<tr>
<td><strong>Instrumental noise</strong></td>
<td><img src="image.png" alt="+" /> (20μKarcmin@150GHz)</td>
<td><img src="image.png" alt="−" /> (33μKarcmin@143GHz)</td>
</tr>
<tr>
<td><strong>Filter transfer function</strong></td>
<td><img src="image.png" alt="−" /> (scales smaller 1/2deg)</td>
<td><img src="image.png" alt="+" /> (all scales)</td>
</tr>
<tr>
<td><strong>Frequency range</strong></td>
<td><img src="image.png" alt="−" /> (95-220GHz)</td>
<td><img src="image.png" alt="+" /> (100-857GHz)</td>
</tr>
</tbody>
</table>
SPT-SZ cluster catalogue

677 candidates (ξ>4.5)
Inside SPT-SZ public footprint
With redshift
SPT flux < 2x10^{-4} arcmin^2

461 clusters

2x10^{14} M_☉ ≤ M_{500} ≤ 10^{15} M_☉
0.05 ≤ z ≤ 1.7

Redshift z and mass M_{500} provided in the SPT-SZ catalogue

Bleem et al. 2015
The average cluster profile

averaging of cluster profiles possible thanks to cluster self-similarity

toy model for the 461 SPT-SZ clusters
The average cluster profile

averaging of cluster profiles possible thanks to cluster self-similarity

\( \theta_{500} : \) characteristic scale
The average cluster profile

averaging of cluster profiles possible thanks to cluster self-similarity

\( \theta_{500} \) : characteristic scale
\( y_{500} \) : characteristic Compton parameter

\( \theta_{500} \) and \( y_{500} \) computed analytically from redshift \( z \), mass \( M_{500} \) and cosmological parameters
The average cluster profile

averaging of cluster profiles possible thanks to cluster self-similarity

\[ \theta_{500} : \text{characteristic scale} \]
\[ \gamma_{500} : \text{characteristic Compton parameter} \]

\[ \theta_{500} \text{ and } \gamma_{500} \text{ computed analytically from redshift } z, \text{ mass } M_{500} \]

and cosmological parameters

Difficulties
- Instrumental and astrophysical noise
- Beams and \( \theta_{500} \) rescaling

Work in Harmonic (Fourier) space
The harmonic space

outer slope $\beta$

Real space

Size $\theta$ divided by $\theta_{500}$

$\frac{\theta}{\theta_{500}}$

Harmonic space

Multipole $l$ multiplied by $\theta_{500}$

$\frac{\theta_{500}}{\theta_{500}}$ [arcmin$^{-2}$]

$p(x) = \frac{P_0}{(c_{500}x)\gamma [1 + (c_{500}x)\gamma]^{(\beta-\gamma)/\alpha}}$

$x = r/R_{500}$  

Nagai et al. 2007
The harmonic space

inner slope $\gamma$

Real space

Harmonic space

Size $\theta$ divided by $\theta_{500}$

Multipole $l$ multiplied by $\theta_{500}$
SPT-SZ and Planck maps

[Images of SPT-SZ and Planck maps at different frequencies: SPT 95GHz, SPT 150GHz, SPT 220GHz, Planck 100GHz, Planck 143GHz, Planck 217GHz, Planck 353GHz, Planck 545GHz, Planck 857GHz. Each image is labeled with its frequency.]
1 - Internal Linear Combination (ILC)

2 - Renormalize

3 - Rescale & azimuthal average

4 – Sample average
1 - Internal Linear Combination (ILC)
2 - Renormalize
3 - Rescale & azimuthal average
4 - Sample average

assumes
- SZ frequency spectrum (including relativistic SZ corrections)
- filter transfer function
e.g. Remazeilles, Delabrouille & Cardoso 2011

SPT-SZ and/or Planck maps

Compton y map (Fourier space)
Method

1. Internal Linear Combination (ILC) → Compton $y$ map in Fourier space = $\text{FT}(y)$

2. Renormalize

3. Rescale & azimuthal average

4. Sample average
Method

1 - Internal Linear Combination (ILC) → Compton $y$ map in Fourier space = $\text{FT}(y)$

2 - Renormalize → $\text{FT}(y)$ map divided by $y_{500}$

3 - Rescale & azimuthal average

4 – Sample average
1 - Internal Linear Combination (ILC) → **Compton** $y$ map in Fourier space = $\text{FT}(y)$

2 - Renormalize → $\text{FT}(y)$ map divided by $y_{500}$

3 - Rescale & azimuthal average → $\text{FT}(y/y_{500})$ weighted averaged in $l\theta_{500}$ bins

4 – Sample average
1 - Internal Linear Combination (ILC) → Compton y map in Fourier space = $\text{FT}(y)$

2 - Renormalize → $\text{FT}(y)$ map divided by $y_{500}$

3 - Rescale & azimutal average → $\text{FT}(y/y_{500})$ weighted averaged in $l*\theta_{500}$ bins

4 - Sample average → $\text{FT}(y/y_{500})_i (i=1,461)$ weighted averaged
SPT-SZ and Planck profiles

Melin, Pratt & Arnaud, in prep.
Joint profile

Preliminary

Best GNFW fit

Planck Pressure Profile (PIPV)

Melin, Pratt & Arnaud, in prep.
3D pressure profile

Preliminary

Universal Pressure Profile (UPP) 
(Arnaud et al. 2010)

Planck Pressure Profile (PIPV)

Best GNFW fit

Melin, Pratt & Arnaud, in prep.
3D pressure profile – best fit

Planck Intermediate Results V, 2012

Melin, Pratt & Arnaud, in prep.
Redshift evolution of the joint profile

\[ \frac{\gamma}{\gamma_{500}} \theta_{500}^{-2} \text{ [arcmin}^{-2}] \]

Planck Pressure Profile (PIPV)

\[ \Delta z \geq 0.6 \]
\[ z < 0.6 \]

Melin, Pratt & Arnaud, in prep.
A look at the outskirts: 2D Compton profile

Melin, Pratt & Arnaud, in prep.

Preliminary Planck Pressure Profile (PIPV)

Best GNFW fit

Planck Pressure Profile (PIPV)

Best GNFW fit

Melin, Pratt & Arnaud, in prep.
• Average cluster pressure profile measured for 461 clusters of the SPT-SZ catalogue
• Takes advantage of both Planck and SPT-SZ data
• Average profile close to Arnaud et al. 2010 in the inner part, and to Planck pressure profile 2013 in the outer part
• Significant improvement on the precision of the parameters of the GNFW fit with respect to Planck pressure profile
• Additional fittings possible with subsamples (e.g. high/low redshift)
• Outskirts: pressure variations at $\theta > 2\theta_{500}$ (shocks ?), no clear single feature

• Future steps: GNFW fits for low/high redshift subsamples, average pressure profile scaled in $\theta_{200}$