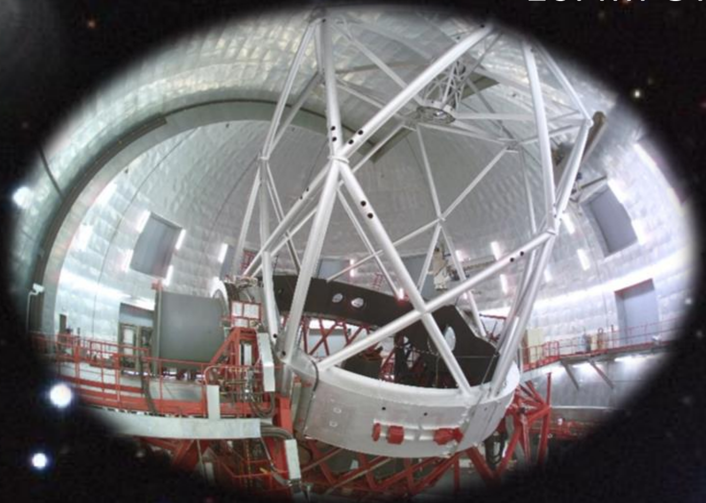
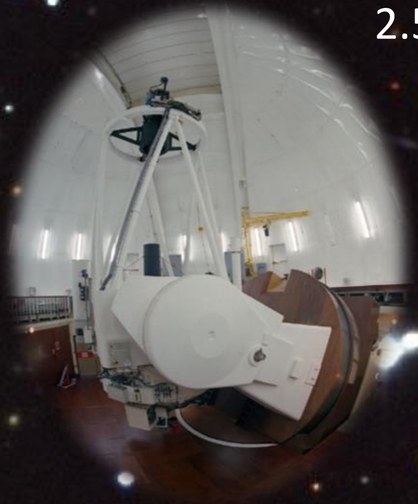
Optical follow-up of galaxy cluster candidates detected by Planck

Universidad de La Laguna

10.4m GTC



2.5m INT



3.5m TNG

Alejandro Aguado

24th June 2019 – Astro@Ts

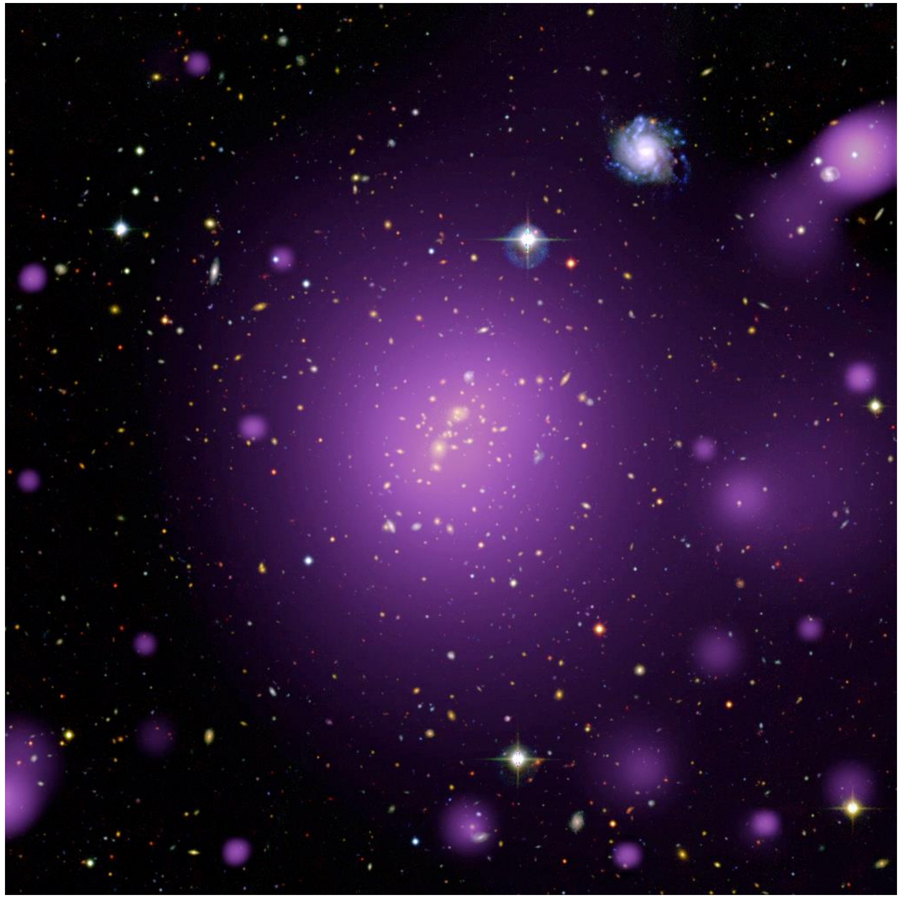
INTRODUCTION

Galaxy Clusters (GCs):

- Most massive bounded systems in the Universe
- Located in *halos*
- Trace the Large-scale structure (LSS)
- Its population is sensitive to the cosmology

GCs across the spectrum:

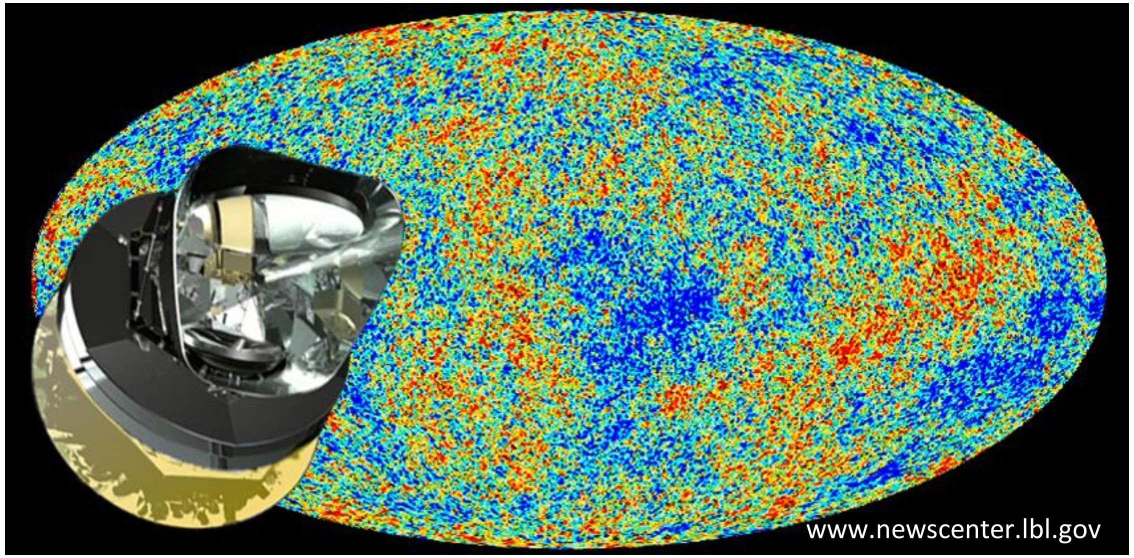
- X-Ray → hot intra-cluster medium & ionized metals
- Optical/IR → Stars & intra-cluster light; Lensing
- **Millimetre → Sunyaev-Zel'dovic (SZ) effect**
- Radio → Synchrotron emission from relativistic electrons



Galaxy cluster XLSSC006
ESA/XMM-Newton (X-rays); CFHT (optical); XXL Survey

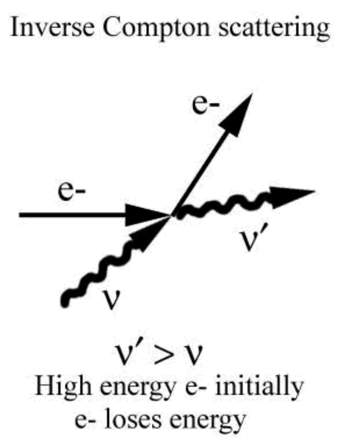
THE PLANCK MISSION

- Space based observatory
- Full sky coverage mission
- May 2009 – October 2013
- Two instruments:
  - LFI (Low Frequency Instrument)
    - 30, 44 & 70 GHz
  - HFI (High Frequency Instrument)
    - 6 channels between 100 – 857 GHz

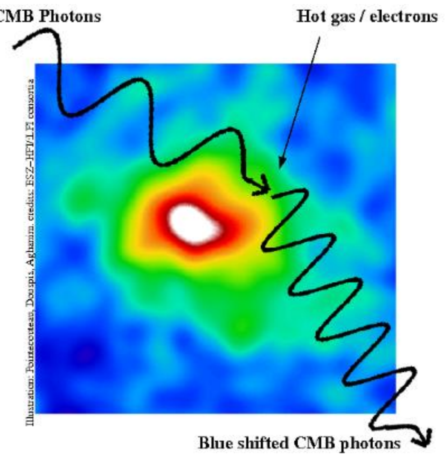


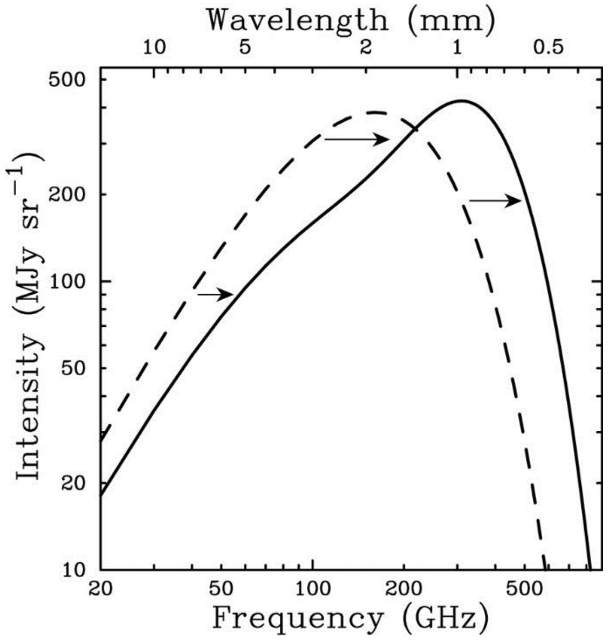
- Main goals:
  - Cosmic Microwave Background (CMB) anisotropies (Temperature & polarization)
  - **GCs catalogue through SZ effect**
  - Gravitational lensing of the CMB, as well as the integrated Sachs-Wolfe effect
  - …

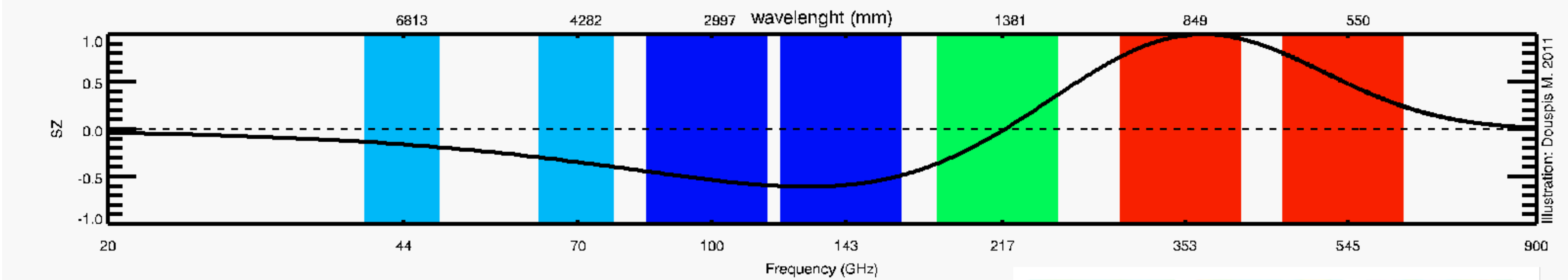
SUNYAEV-ZEL'DOVICH (SZ) EFFECT AND CLUSTER IDENTIFICATION WITH PLANCK



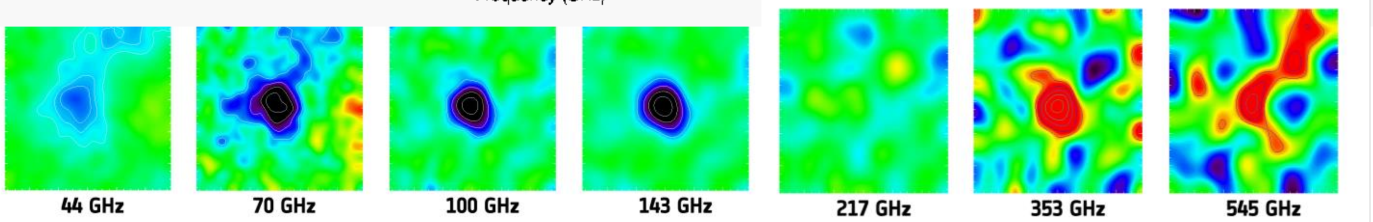
- Distortion of the CMB through inverse Compton scattering by high energy electrons
- Spectrum is shifted
- Drop at low frequencies and increase at higher ones





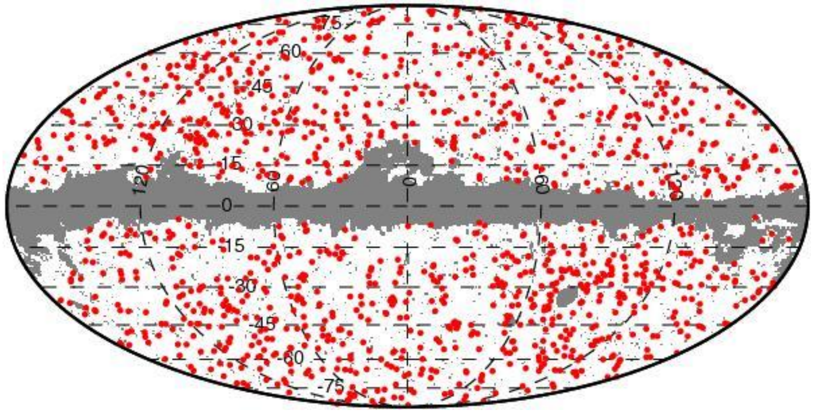


A2319 seen by PLANCK



PLANCK CATALOGUES OF SZ SOURCES

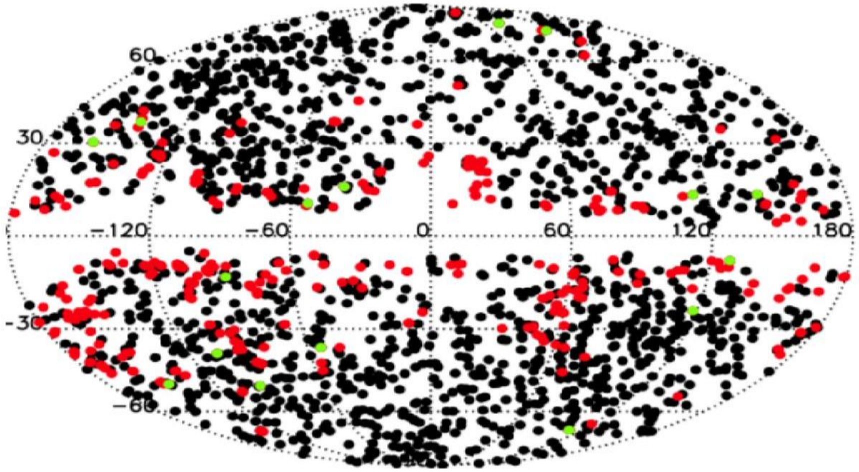
PSZ1



Planck 2013 results. XXIX

Planck 2013 results. XXXII

PSZ2



Planck 2015 results. XXVII

Sample	PSZ1 2013	PSZ1 2015	PSZ2	Common	New PSZ2
Union	1227	1227	1653	937	716
Intersection	546	546	827	502	325
Confirmed	861	947	1203	820	383
Candidates	366	292	546	99	447
Low reliability	142	131	143	39	104
Total X-ray	501	501	603	477	126
MCXC	455	455	551	427	124
SZ clusters	82	82	110	79	31

Total = 1943
Confirmed = 1330
Unknown = 748

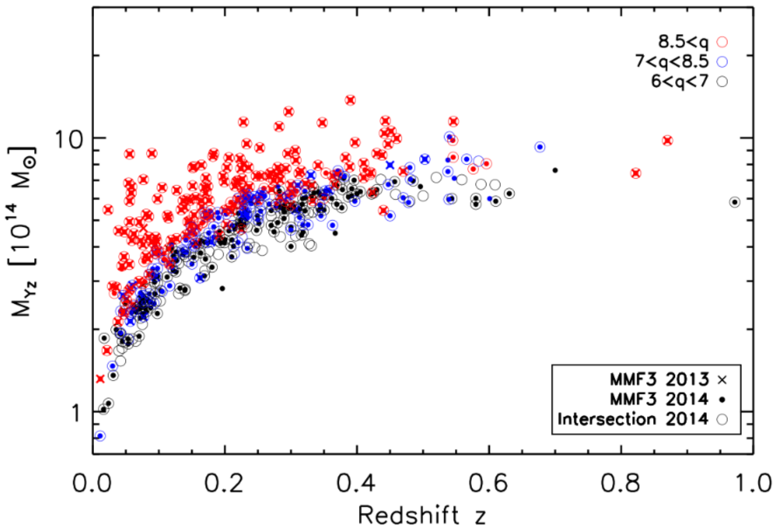
Approximately 450 accesible from the La Palma Observatory with $\delta > -15^o$

WHY AN OPTICAL FOLLOW-UP?

- Cluster counts are very usefull to constraint cosmological parameters (Ω_m , σ_8 , …)

$$\frac{dN}{dzdq} = \int d\Omega \int dM \frac{dN}{dzdMd\Omega} P[q|\bar{q}_m(M,z,l,b)]$$

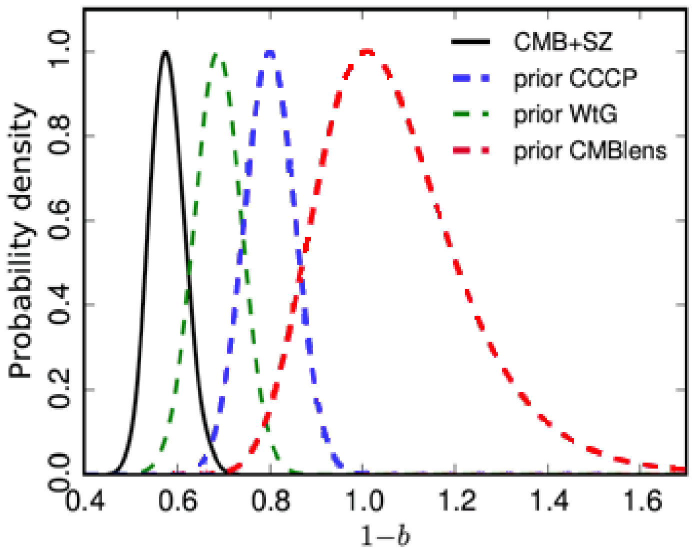
- Cosmology is very sensitive to the survey selection function

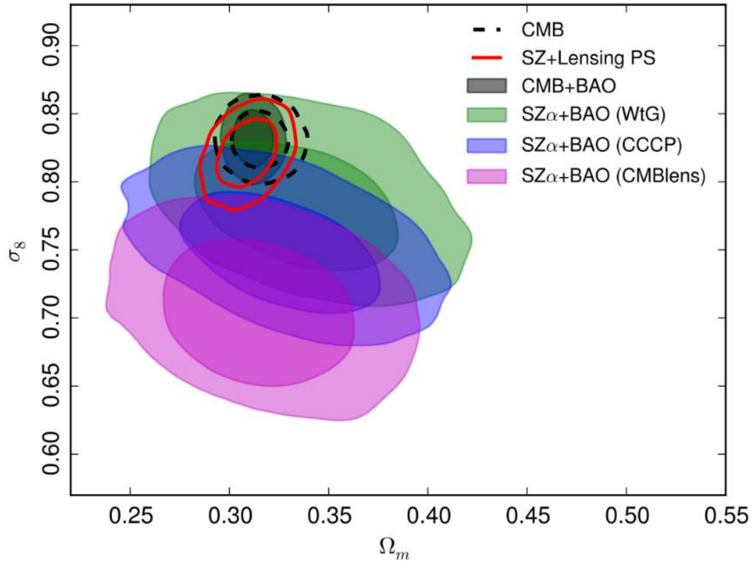


- Need for mass scaling law ($M_{500} - M_{SZ}$) , understanding possible biases

$$M_{500}^{HE} = (1-b)M_{500}^{true}$$

$$(1-b) = 0.8$$





MOTIVATION FOR OUR OPTICAL FOLLOW-UP

- The SZ surface brightness does not depend on redshift
- Does the mass bias depend on z and/or mass?
- Systematic aproach to obtain a complete selection function
- Understand the tension in cosmological parameters derived from the CMB and cluster counts, mostly in σ_8

MOTIVATION FOR OUR OPTICAL FOLLOW-UP

- The SZ surface brightness does not depend on redshift
- Does the mass bias depend on z and/or mass?
- Systematic aproach to obtain a complete selection function
- Understand the tension in cosmological parameters derived from the CMB and cluster counts, mostly in σ_8

AIM OF OUR OPTICAL FOLLOW-UP

- Validate unknown candidates
- Obtain dynamical masses
- Use these confirmed candidates to improve uncertainty in mass scaling law:

$$M_{500}^{SZ} = (1-b)M_{500}^{dyn}$$

- Do cosmology with the same clusters used for the scaling law

OBSERVATIONAL PROGRAMMES

SUMMARY

<table>
<tr><th colspan="8">PSZ1</th></tr>
<tr><th>Telescope</th><th>Mode</th><th>Instrument</th><th># Nights</th><th colspan="3"># Clusters</th><th>Redshift range</th></tr>
<tr><td>INT</td><td rowspan="2">Imaging</td><td>WFC</td><td>21</td><td>86</td><td colspan="2" rowspan="2">204</td><td>-</td></tr>
<tr><td rowspan="2">WHT</td><td rowspan="2">ACAM</td><td>~15</td><td>118</td><td>-</td></tr>
<tr><td rowspan="2">LS</td><td>~9</td><td>37</td><td rowspan="2">87</td><td rowspan="4">187</td><td>$z < 0.3$</td></tr>
<tr><td rowspan="2">GTC</td><td rowspan="2">OSIRIS</td><td>68 hours</td><td>50</td><td>$0.1 \leq z \leq 0.85$</td></tr>
<tr><td rowspan="2">MOS</td><td>37 hours</td><td>27</td><td rowspan="2">100</td><td>$0.4 \leq z \leq 0.9$</td></tr>
<tr><td>TNG</td><td>DOLORES</td><td>26</td><td>73</td><td>$0.1 \leq z < 0.4$</td></tr>
<tr><th colspan="8">PSZ2</th></tr>
<tr><th>Telescope</th><th>Mode</th><th>Instrument</th><th># Nights</th><th colspan="3"># Clusters</th><th>Redshift range</th></tr>
<tr><td>INT</td><td>Imaging</td><td>WFC</td><td>22</td><td colspan="3">201</td><td>-</td></tr>
<tr><td>TNG</td><td rowspan="2">MOS</td><td>DOLORES</td><td>9</td><td>24</td><td colspan="2" rowspan="2">80</td><td>$0.1 \leq z < 0.4$</td></tr>
<tr><td>GTC</td><td>OSIRIS</td><td>70 hours</td><td>56</td><td>$0.4 \leq z \leq 0.9$</td></tr>
</table>

More than

<u>10000</u>

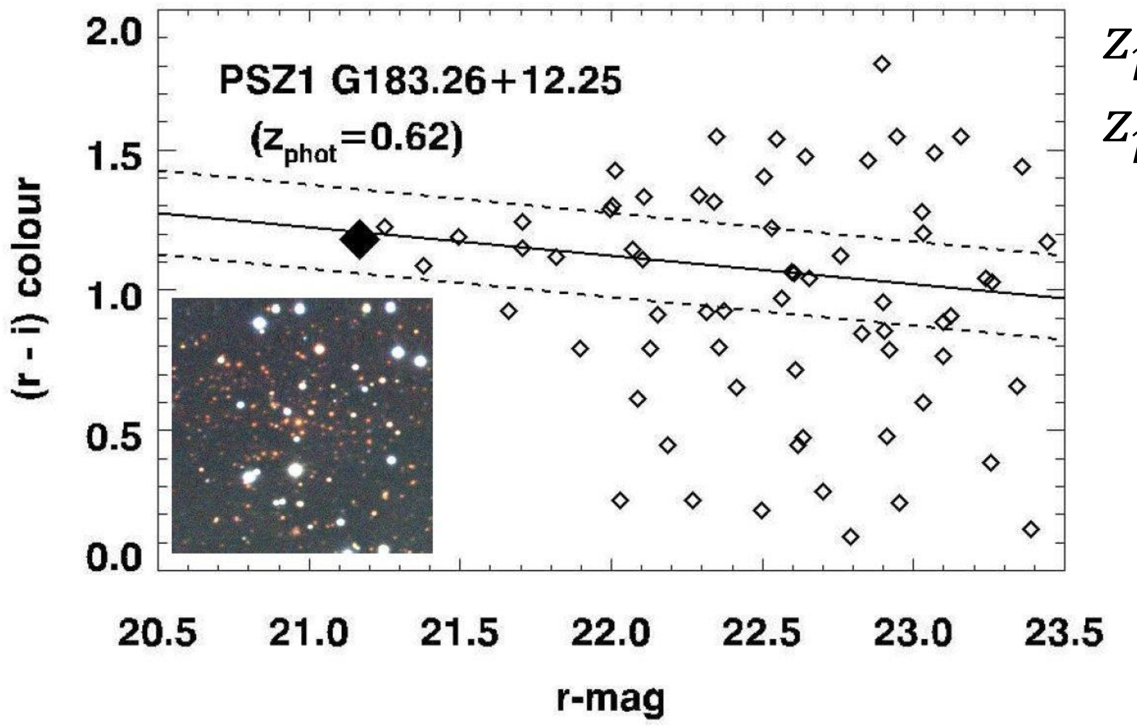
spectra

OBSERVATIONAL STRATEGY

IMAGING

g-, r-, i-band images in order to make RGB images and color-magnitude diagrams

Estimation of photo-z from CMDs



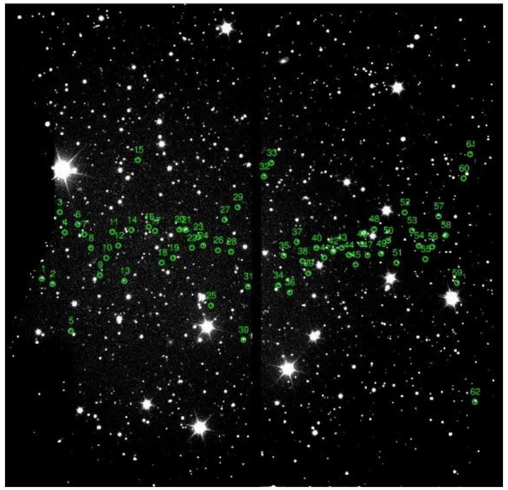
$$z_{phot} \approx 0.361(g' - r') - 0.278, \text{ if } (r' - i') \lesssim 0.75$$
$$z_{phot} \approx 0.364(r' - i') + 0.182, \quad \text{if } (r' - i') \gtrsim 0.75$$

Planck intermediate results. XXXVI

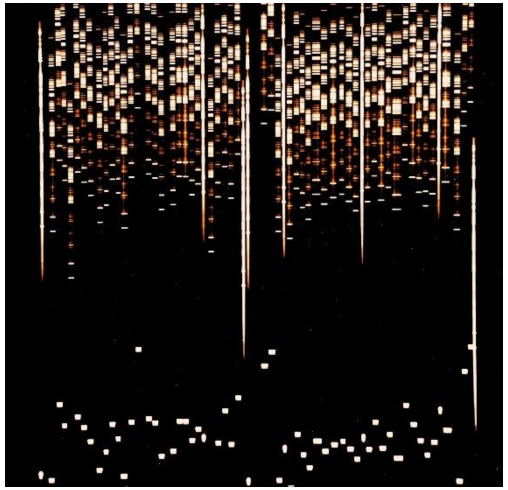
$$z_{phot} < 0.4 \rightarrow DOLORES@TNG$$
$$z_{phot} > 0.4 \rightarrow OSIRIS@GTC$$

OBSERVATIONAL STRATEGY

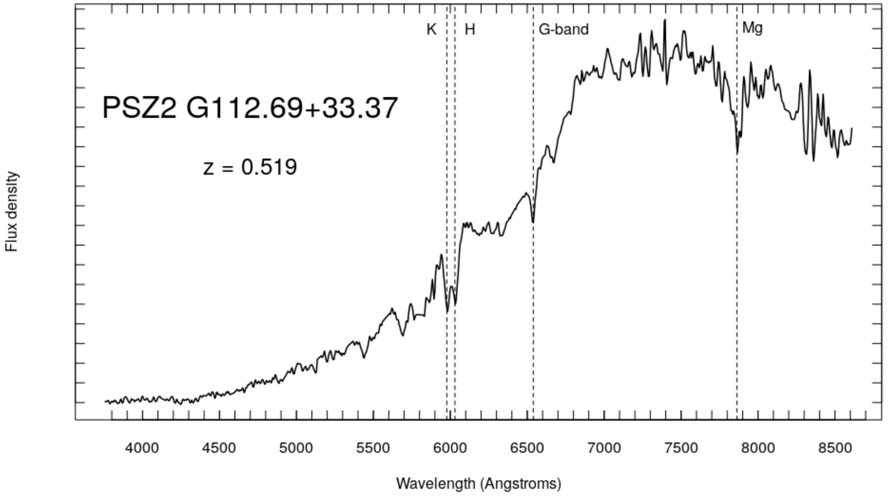
MOS SPECTROSCOPY



Design the mask using a preimage

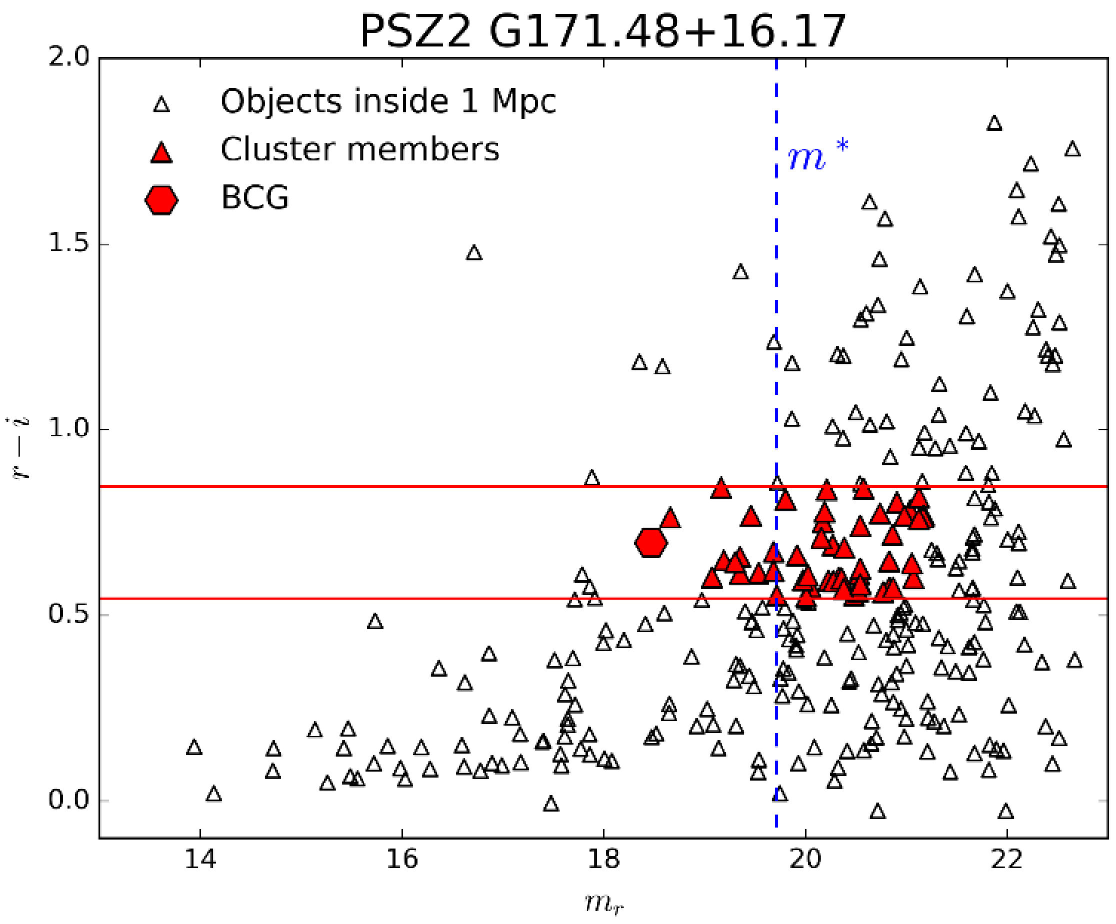


Obtain the raw spectra



Acquire radial velocity and redshift

RICHNESS ESTIMATION



- Richness:
  - $z \leq 0.35 \rightarrow g' - r'$
  - $z > 0.35 \rightarrow r' - i'$
  - $RS \pm 0.15\, mag$
  - $[m^*_{r'} - 1, m^*_{r'} + 1.5]\, mag$
  - 1 Mpc radius

RICHNESS ESTIMATION

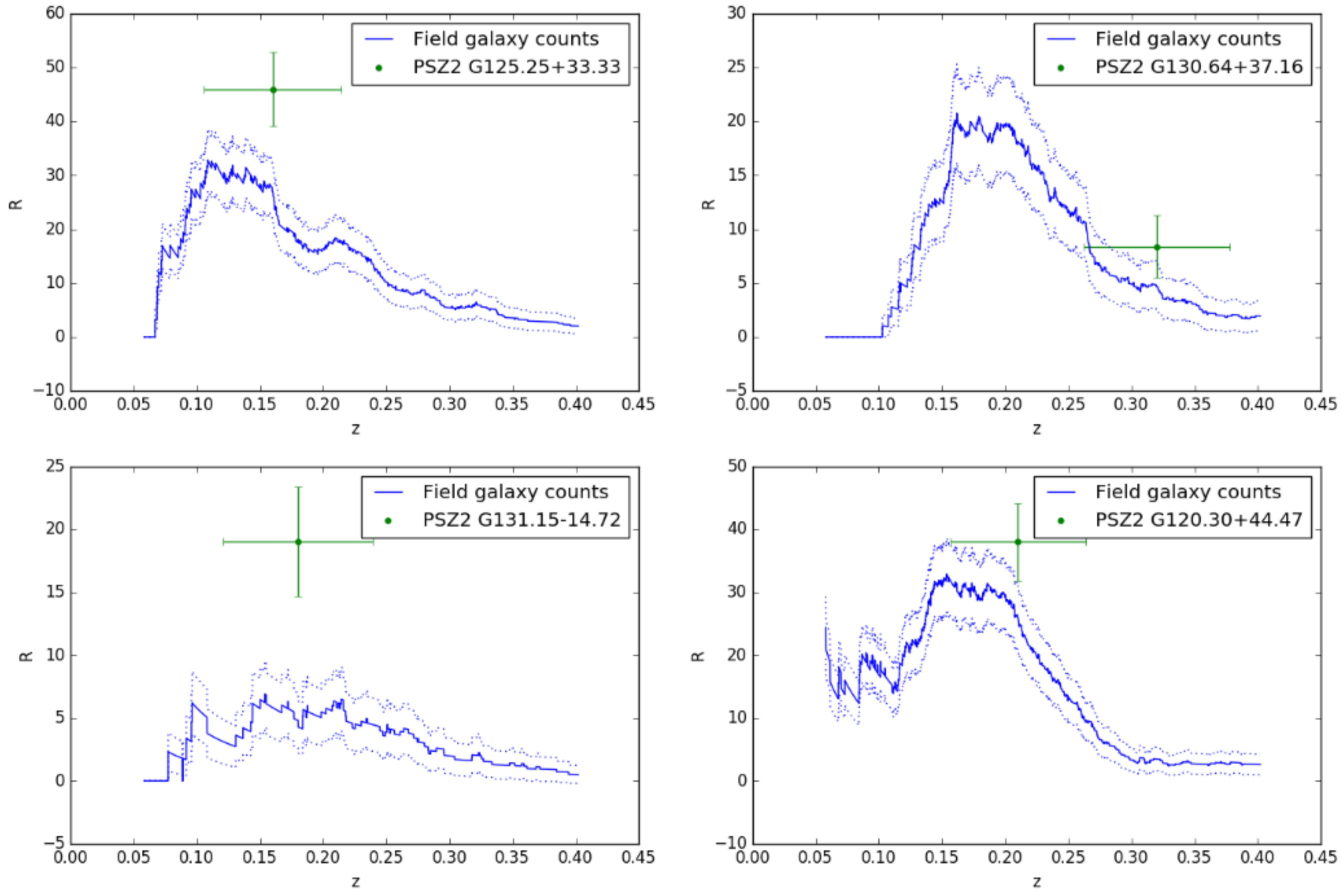
- Richness depends on the field and redshift
- Richness significance:

$$\sigma_R \equiv \frac{R_0 - R_f}{\sqrt{R_f}}$$

where

R_0 ≡ Original richness

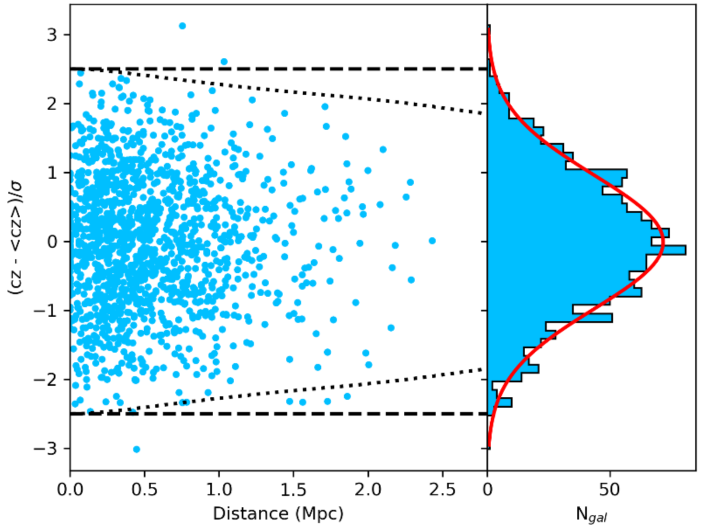
R_f ≡ Field richness



VELOCITY DISPERSION ESTIMATION

MEMBER SELECTION

- ± 2500 km/s in rest frame from the mean velocity and 2.5σ clipping



- Check for special cases:
  - Low/high mass clusters
  - Substructures
  - Possible interlopers…

ESTIMATION

- We make use of the estimator and the corrections to the velocity dispersion proposed by Ferragamo et al. (2019), submitted

VALIDATION CRITERIA

- Planck clusters must be massive systems:
  - High velocity dispersion
  - High richness significance

- We use the relation $\sigma_{1D} - M_{200}$ by Munari et al. 2013

$$M_{200} = \left[\frac{\sigma_{200}}{A \times h(z)}\right]^{1/\alpha} 10^{15} M_{\odot}$$

Flag	Spectroscopy	σ_v (km s^{-1})	σ_R
1	YES	> 500 km s^{-1} (z < 0.2)	> 1.5
		> 650 km s^{-1} (z > 0.2)	> 1.5
2	NO	–	> 1.5
3	YES	< 500 km s^{-1} (z < 0.2)	> 1.5
		< 650 km s^{-1} (z > 0.2)	> 1.5
	NO	–	< 1.5
ND	–	–	–

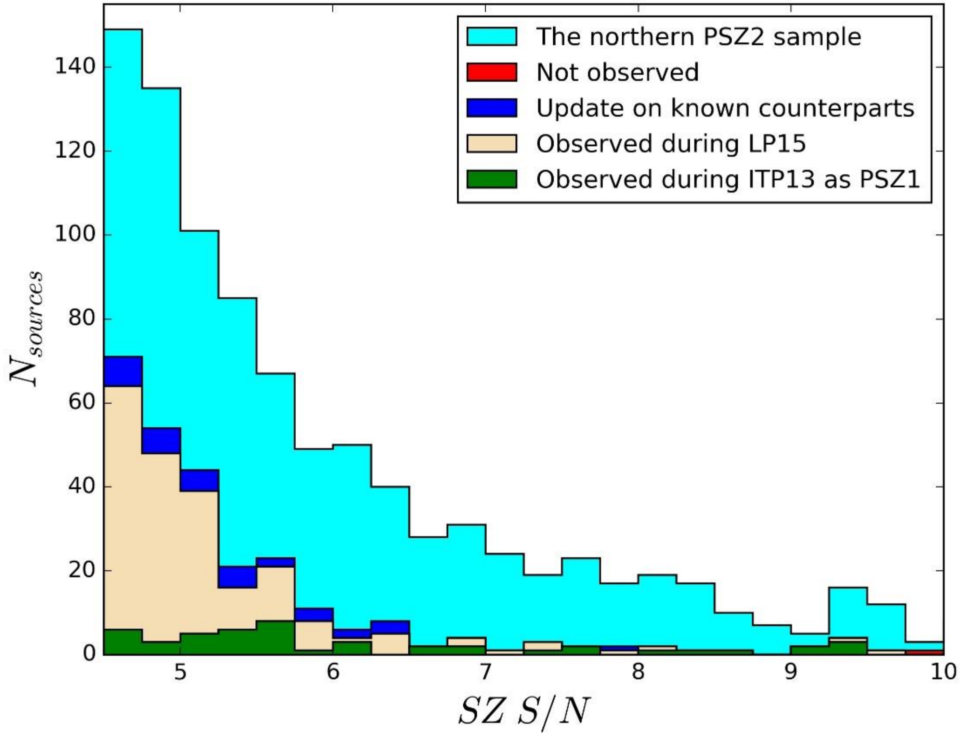
PSZ2 FOLLOW-UP SUMMARY

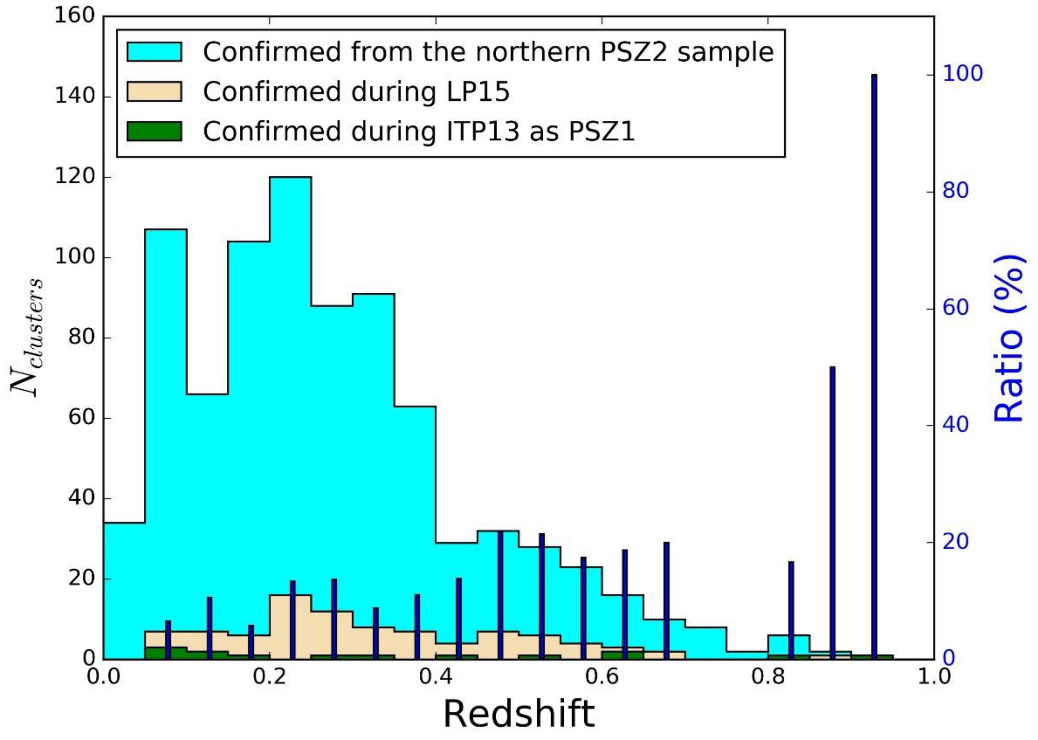
- 184 previously unknown sources observed, 55 spectroscopically
- 79 candidates confirmed as actual GCs, 48 spectroscopically
- 105 sources remain unconfirm
- Streblyanska et al. (2019), A&A accepted
- Aguado-Barahona et al. (2019), A&A submitted

			Position (J2000)									
ID	Planck Name	SZ SNR	R. A.	Decl.	Dist.(′)	$< z_{\rm spec} >$; $z_{\rm spec,BCG}$	$N_{\rm spec}$	$z_{\rm phot}$	$R_{\rm cor}$	$\sigma_{\rm R}$	Flag	Notes
115[a,b]	PSZ2 G032.31+66.07	5.14	14 37 23.35	+24 24 21.70	3.10	0.610 ; –	38	0.62±0.05	13.6±3.7	5.4	1	Substructured
194	PSZ2 G048.47+34.86	5.74	–	–	–	–	–	–	–	–	ND	
242	PSZ2 G058.31+41.96	4.54	–	–	–	–	–	–	–	–	ND	
421-A[c]	PSZ2 G092.69+59.92	4.90	14 26 03.78	+51 14 18.50	3.85	0.462 ; 0.4568	25	0.50±0.05	11.6±3.4	4.3	1	Rykoff et al. (2014)
421-B[c]			14 26 13.10	+51 11 53.17	4.42	0.844 ; –	5	–	–	–	3	Burenin et al. (2018)
424[b]	PSZ2 G093.41−16.26	4.59	22 24 07.25	+37 58 30.46	3.10	–	–	0.24±0.03	40.6±6.4	7.9	2	WHL J222407.2+375831
432[a,b]	PSZ2 G094.31−11.31	4.72	22 12 56.10	+42 35 46.34	1.08	0.204 ; –	27	0.24±0.03	–	–	1	
500	PSZ2 G104.52+39.39	4.60	15 58 38.88	+70 27 24.20	5.62	–	–	0.30±0.04	16.8±4.1	7.8	2	
511	PSZ2 G105.94−16.14	4.62			–	–	–	–	–	–	ND	
545	PSZ2 G112.54+59.53	5.37	–	–	–	–	–	–	–	–	ND	
546[c]	PSZ2 G112.69+33.37	4.63	16 19 49.39	+79 06 24.49	4.78	0.521 ; 0.5194	15	0.51±0.03	–	–	1	WHL J161949.3+790624
592	PSZ2 G120.75+25.39	4.69	–	–	–	–	–	–	–	–	ND	
600	PSZ2 G122.81+24.74	4.60	–	–	–	–	–	–	–	–	ND	
613	PSZ2 G125.25+33.33	5.38	11 41 11.26	+83 27 38.91	1.80	–	–	0.20±0.03	21.0±4.6	4.1	2	
616	PSZ2 G125.41+27.95	4.76	–	–	–	–	–	–	–	–	ND	
620[b]	PSZ2 G125.84−18.72	5.30	01 06 55.65	+44 04 25.72	1.81	0.189 ; –	46	0.19±0.01	–	–	1	WHL J010709.2+440918

RESULTS FOR THE PSZ2-NORTH SAMPLE

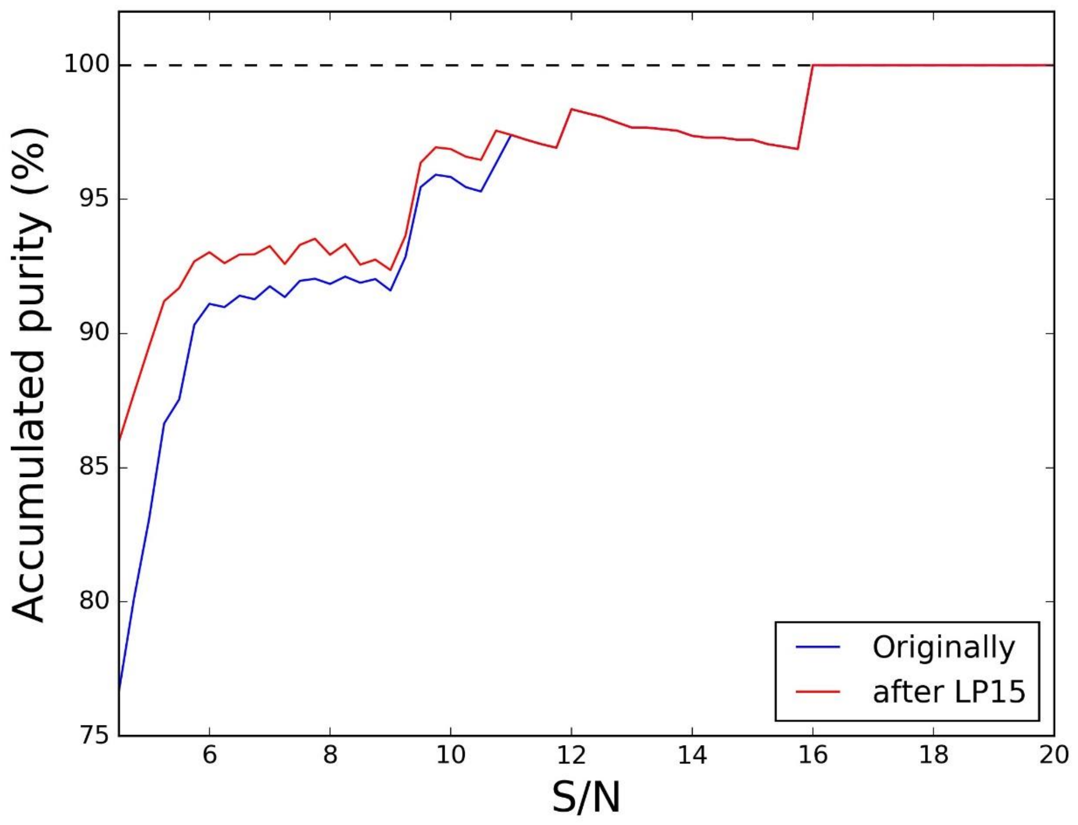
- PSZ2-North sample:
  - Declination > -15 deg
  - 1003 sources (60% of the full PSZ2 catalogue)
  - 852 redshift estimates

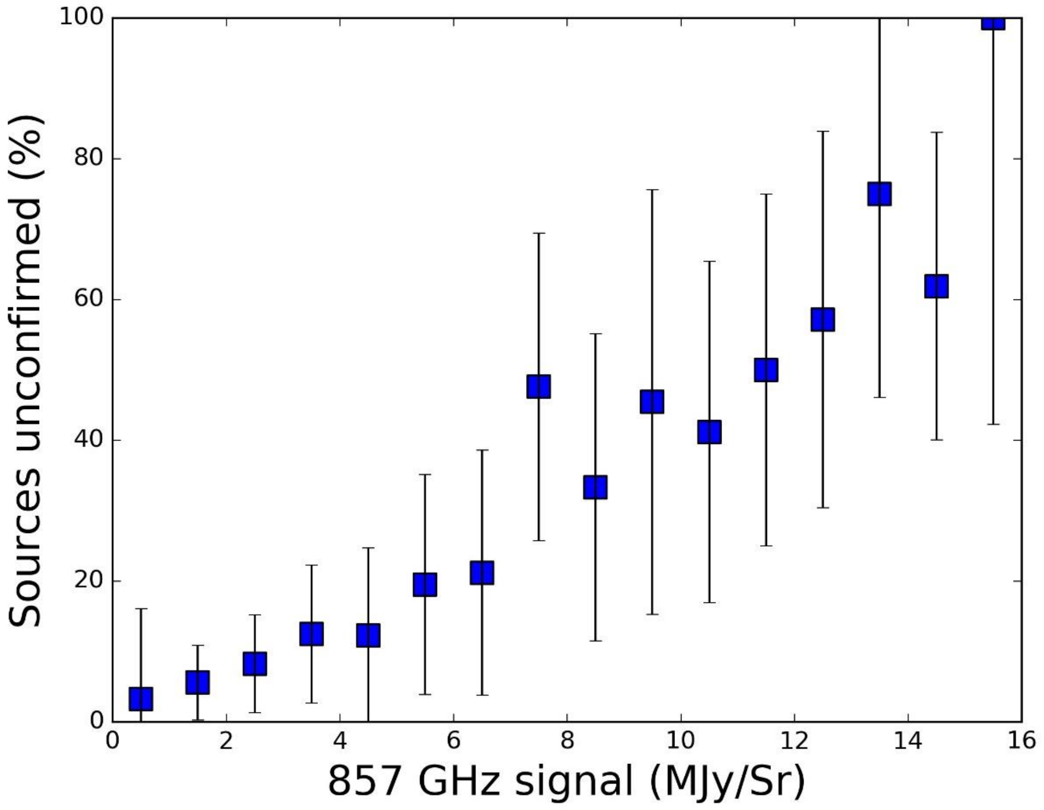




RESULTS FOR THE PSZ2-NORTH SAMPLE

- Purity: ratio between confirmed clusters and total number of SZ sources
- 857 GHz channel, tracer of thermal dust emission





SUMMARY

- 79 new clusters candidates confirmed, 105 remain unknown
- Our confirmations correspond to 20% of the total clusters confirmed in the PSZ2-North sample $(z > 0.4)$
- The purity of the PSZ2-North sample has been updated from 76% to 86%
- Correlation between the number of unconfirmed sources and the thermal dust emission
- Check out Strebyanska et al. (2019) & Aguado-Barahona et al. (2019)
  https://arxiv.org/abs/1905.13661

COMING SOON…

- Characterize the bias in the scaling relation $M_{500}^{SZ} = (1-b)M_{500}^{dyn}$
- Estimate Ω_m and σ_8 using this b-value