STUDY OF THE LARGE-SCALE STRUCTURE OF THE UNIVERSE USING GALAXY CLUSTERS

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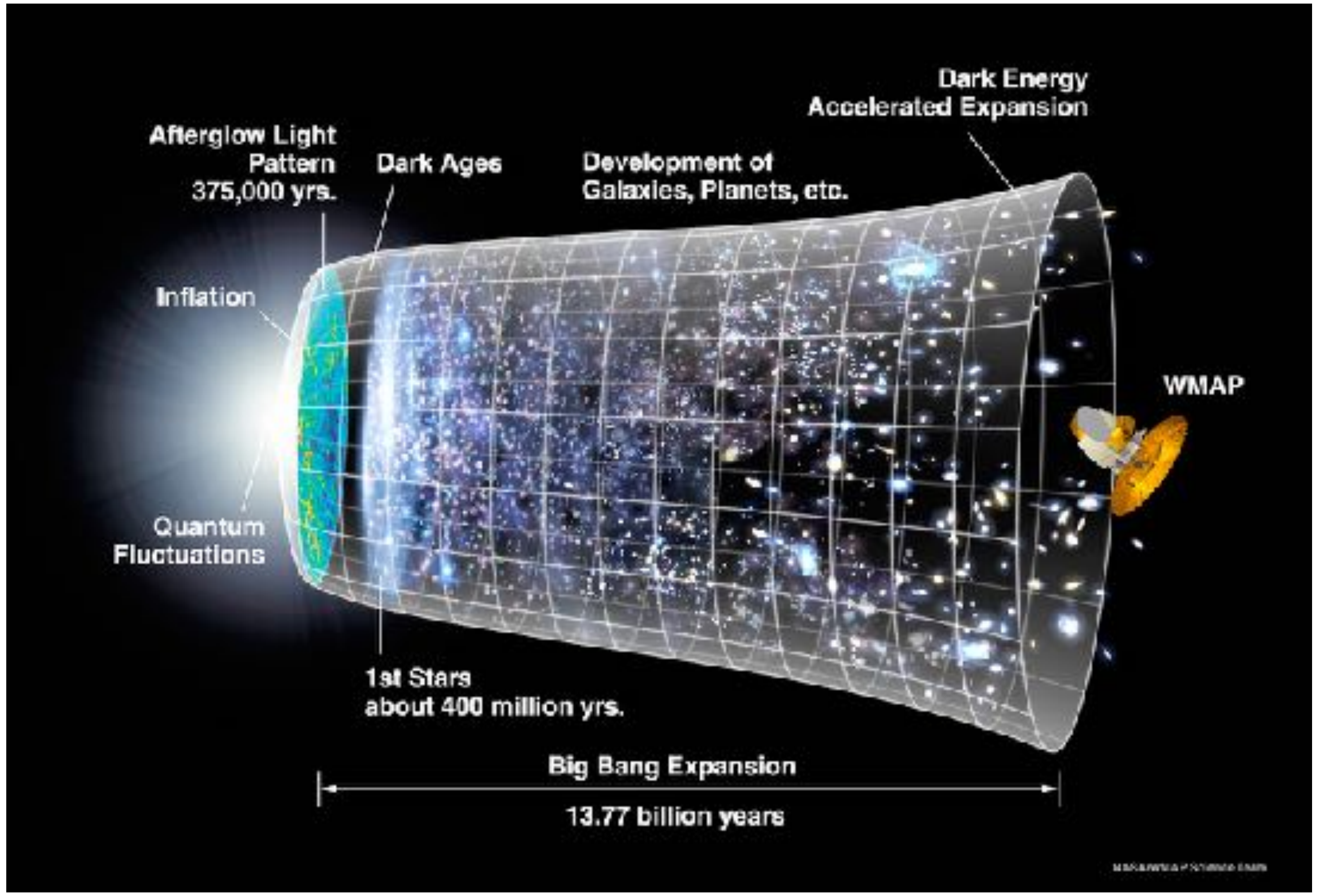
OUTLINES

- *Overview history of the universe*
- *Detection of BAO with galaxy*
- *Galaxy cluster observations*
- *Planck mission*
- *Data: Planck SZ cluster catalog*
- *Estimator of two-point correlation function*
- *Results*
- *Conclusions*

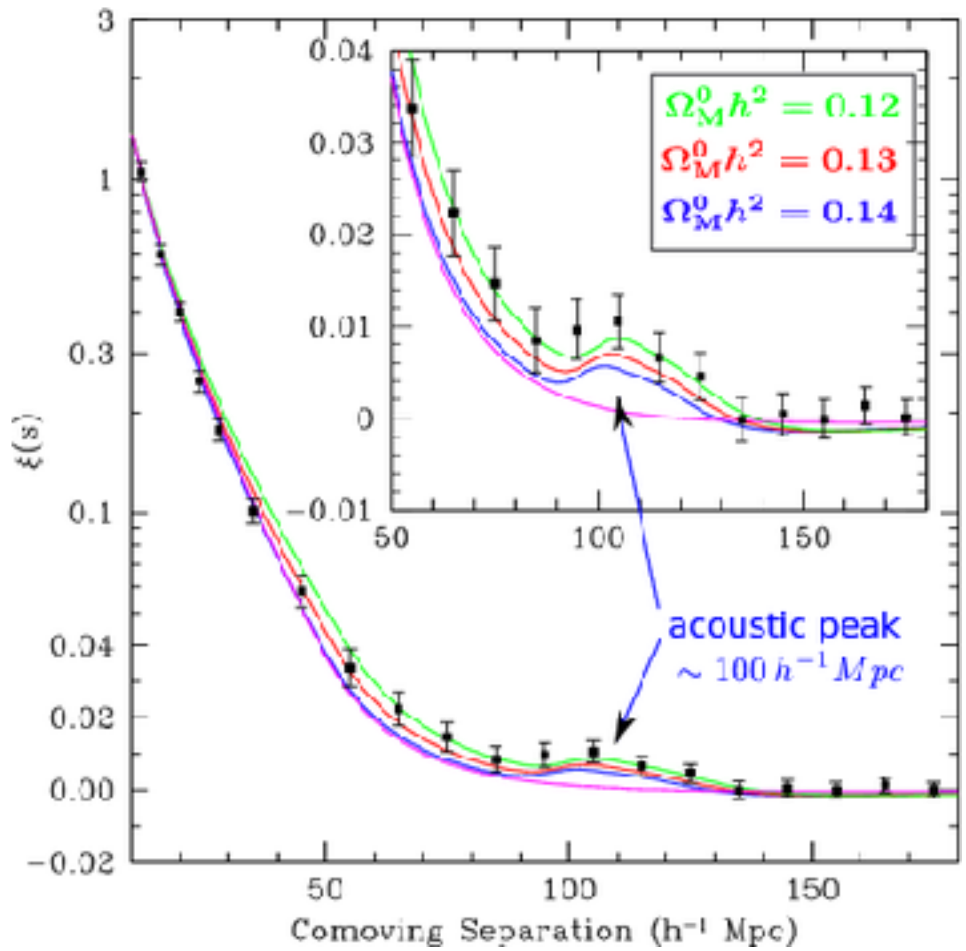
OVERVIEW HISTORY OF THE UNIVERSE



Credit: NASA/WMAP Science Team

- The universe began about 13,8 billion years ago from a super hot dense state (big bang).
- At the beginning, it expanded extremely fast called inflation. Due to the quantum fluctuations during this time, it formed the seed of the current structure of universe.
- When the universe cooled down, the free protons, electron, and neutrons recombined in atoms. The first light of universe travel freely in transparent universe about 380.000 years after the big bang (CMB).
- Galaxies and stars formed after a few hundred millions years.
- **Galaxies, cluster of galaxies, super-clusters, filaments, and voids are the largest structures in the universe.**

DETECTION OF BAO WITH GALAXY

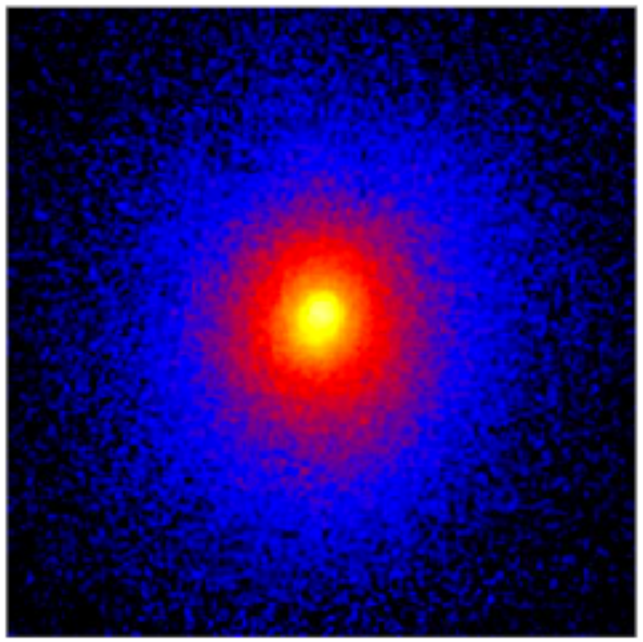


(SDSS) - Eisenstein et al., 2005

- Acoustic wave propagating in the early universe due to the counteracting forces of radiation pressure and gravity.
- The **standard ruler** for length scale in cosmology.
- Study the **dark energy** by constraining cosmological parameters.

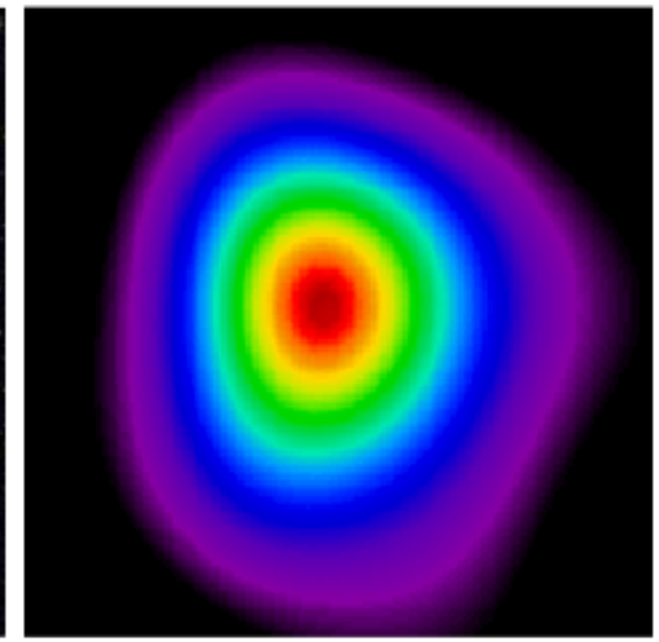
GALAXY CLUSTER OBSERVATIONS

Cluster Abell 1835 [arXiv:1103.4829v2]



X-Ray

Optical

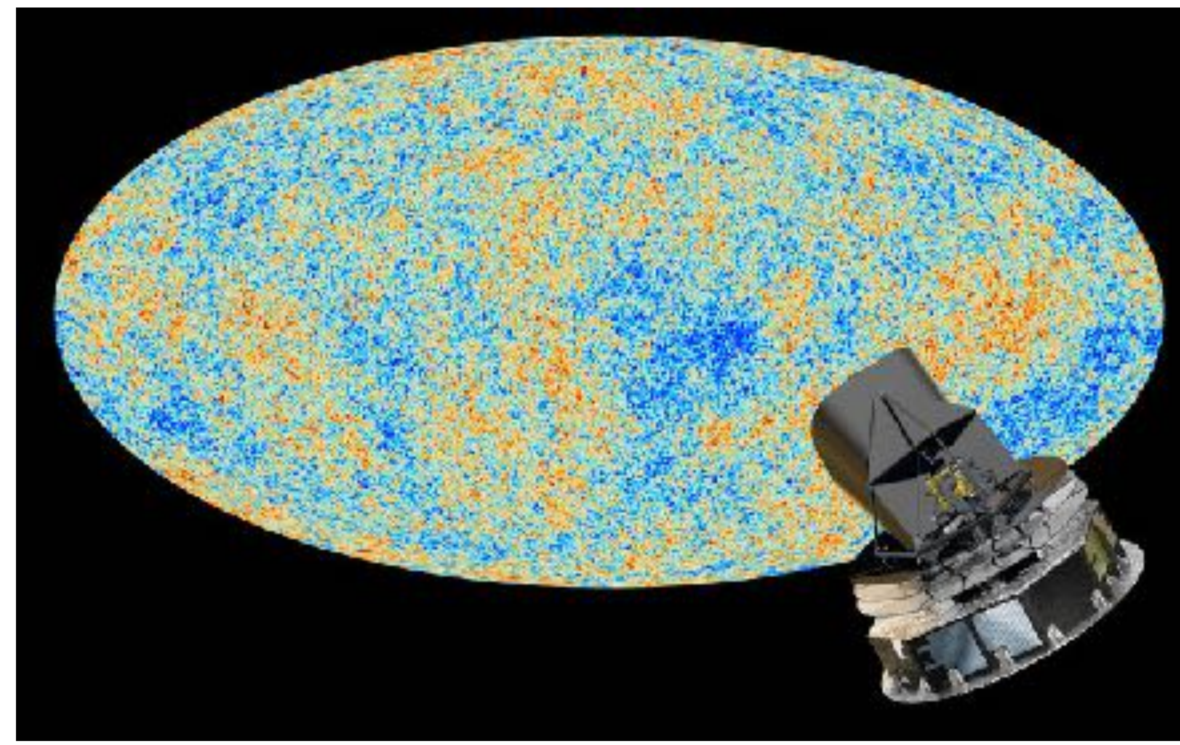


SZ effect

- We can observe galaxy cluster through several ways:
  - X-ray: radiation from hot gas.
  - Optical/Near Infrared: image of galaxy populations.
  - Sunyaev-Zel'dovich (SZ) effect: the distorted spectra of the CMB photons travel through the hot gas of cluster.

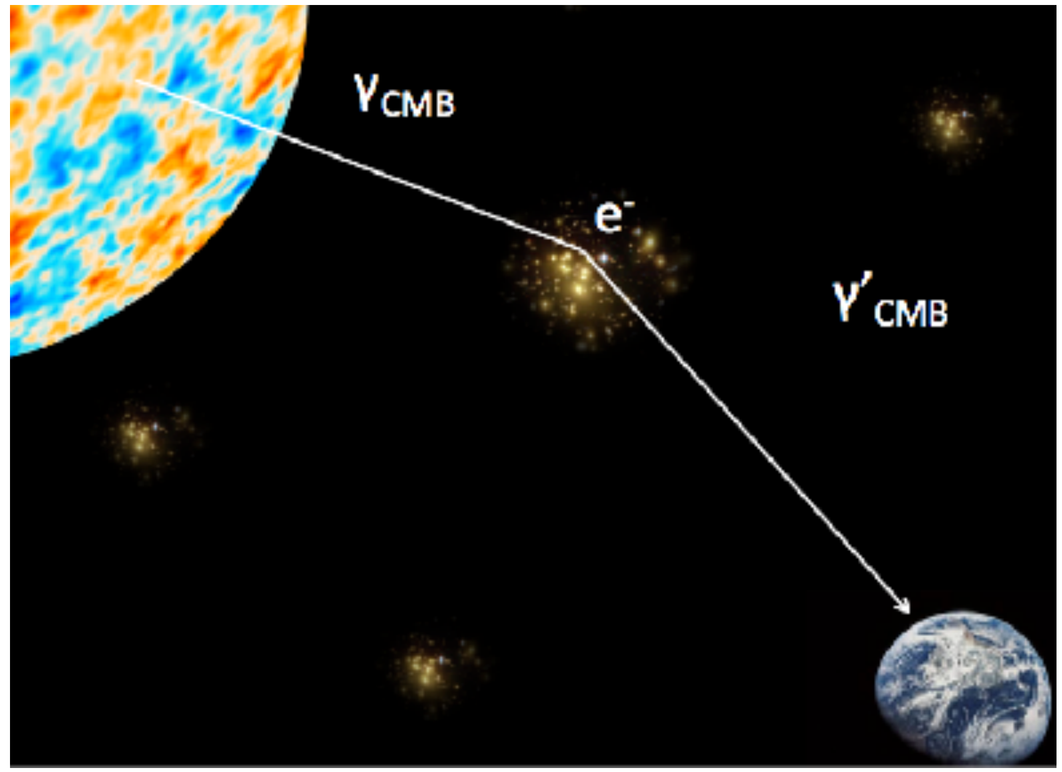
PLANCK MISSION

- Planck is a space mission by ESA. (2009 - 2013)
- Mission: All-sky CMB survey using millimeter wavelengths; Primordial universe (inflation) and dark universe.
- Detected Sunyaev-Zel'dovich clusters across the six highest frequency Planck bands (100-857 GHz) [Planck collaboration XXIV 2015]



Credit: ESA

DATA: PLANCK SZ CLUSTER CATALOG

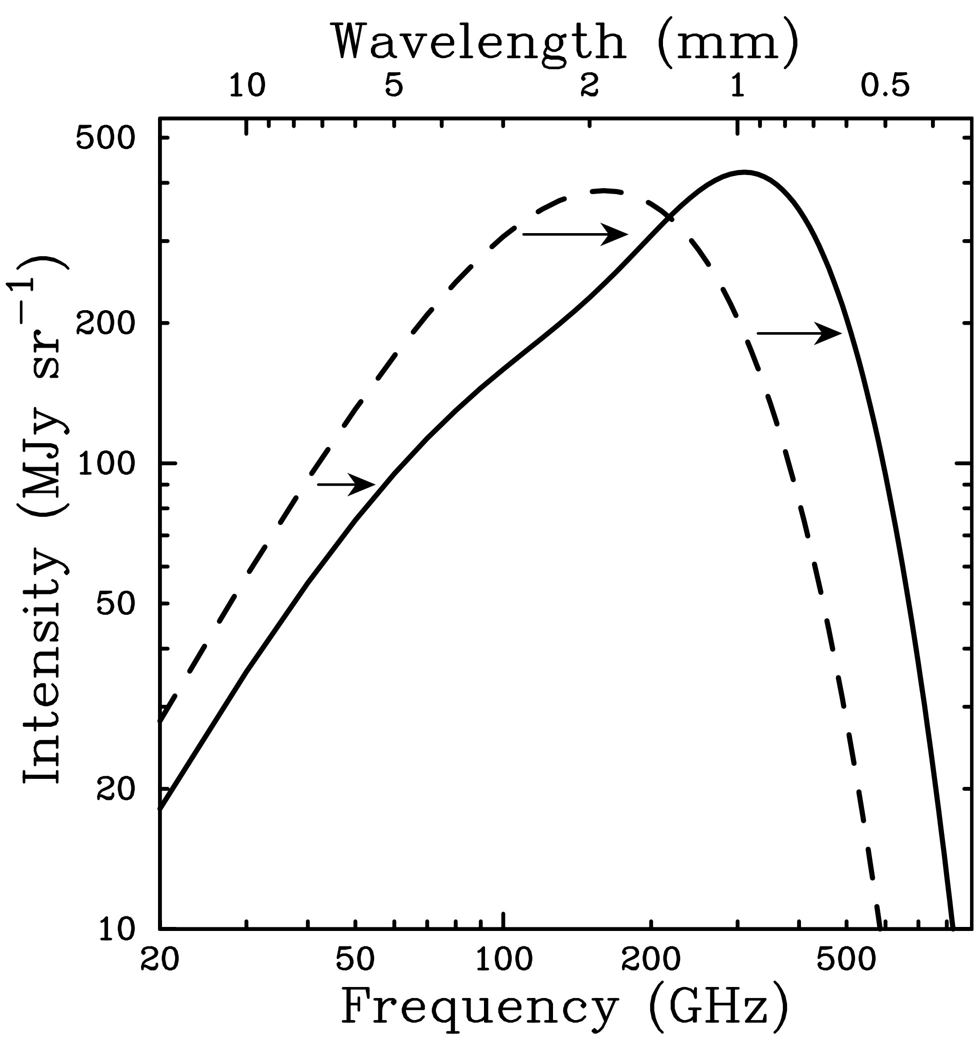


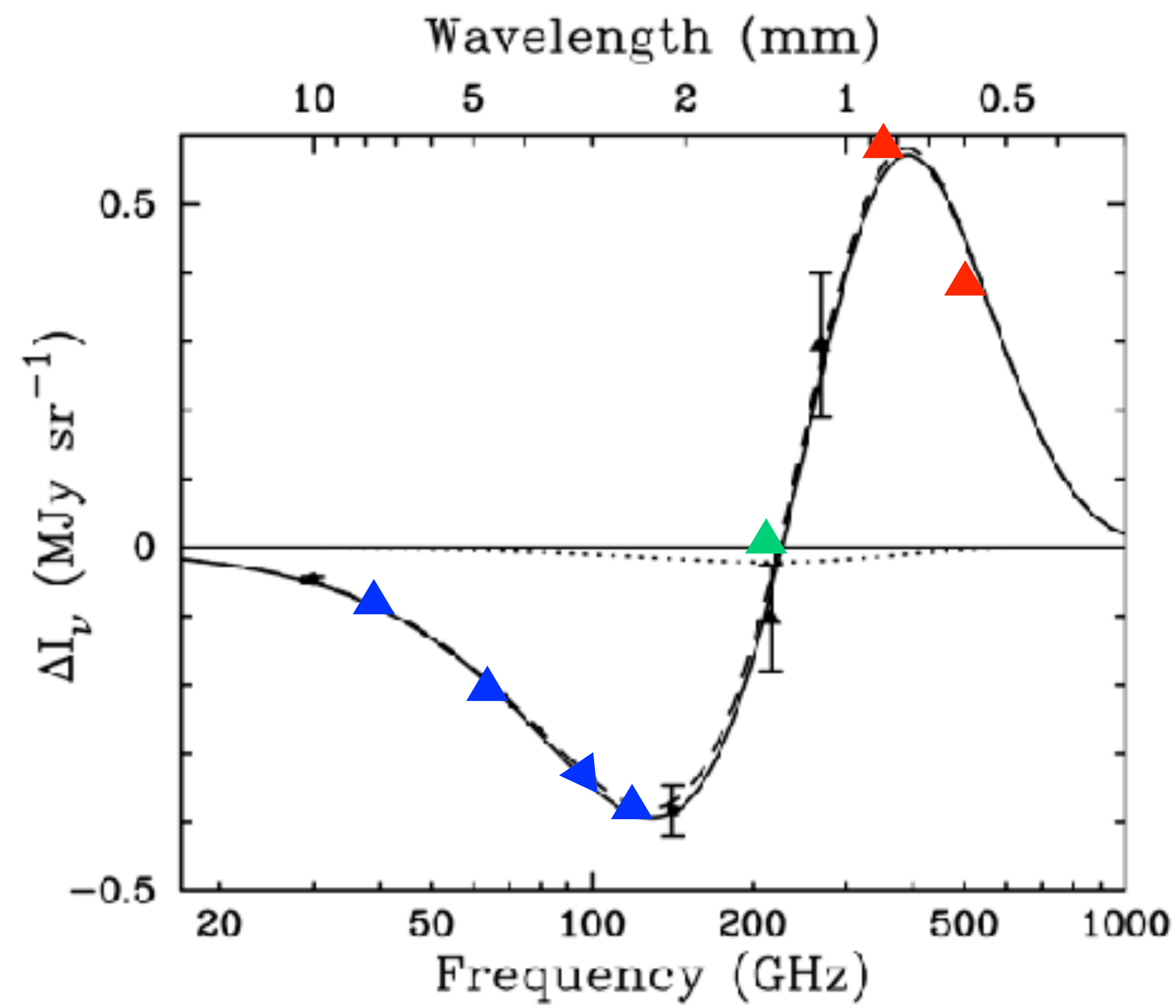
Credit: Matthieu Roman's these.

- Sunyaev-Zel'dovich effect: gain of energy of CMB radiation through the inverse Compton scattering when CMB photons travel through the hot, energetic gas of galaxy cluster.
- We can detect galaxy cluster using this effect at **any redshift**.

SZ EFFECT

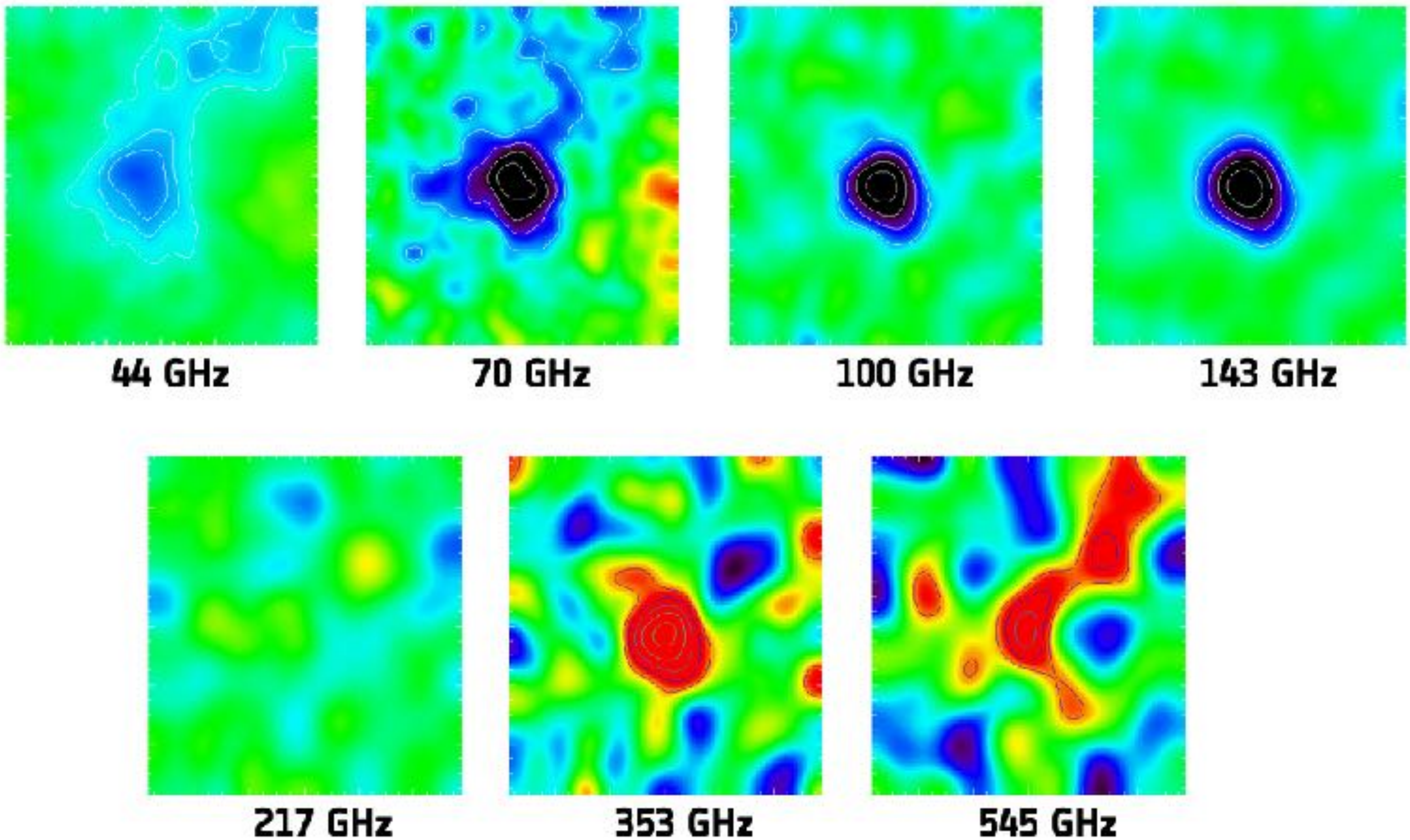
Carlstrom et al., 2002





- ➤ Spectrum of CMB intensity and distorted CMB due to SZ effect.
- ➤ **A decrease** of intensity of CMB at frequencies **f<217 GHz** and **an increase** at higher frequencies.
- ➤ Right plot: difference of intensity between CMB and the signal through the cluster Abell 2163.

ABELL 2319



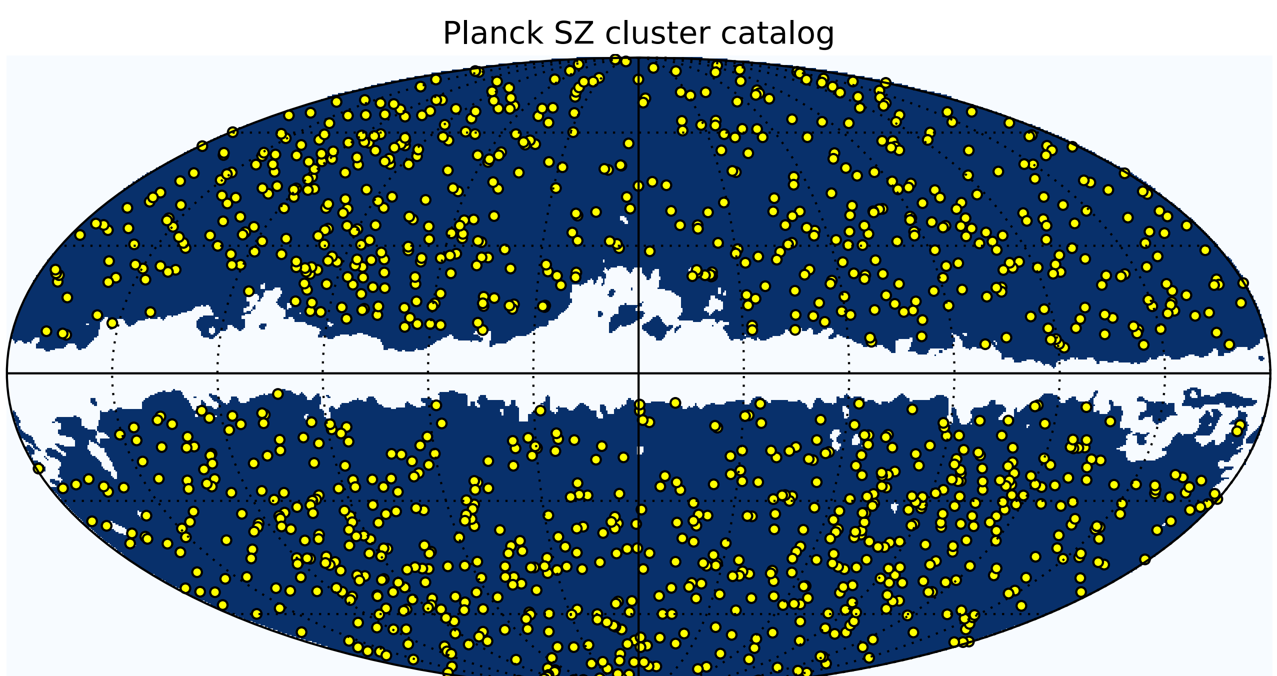
Credit: ESA.

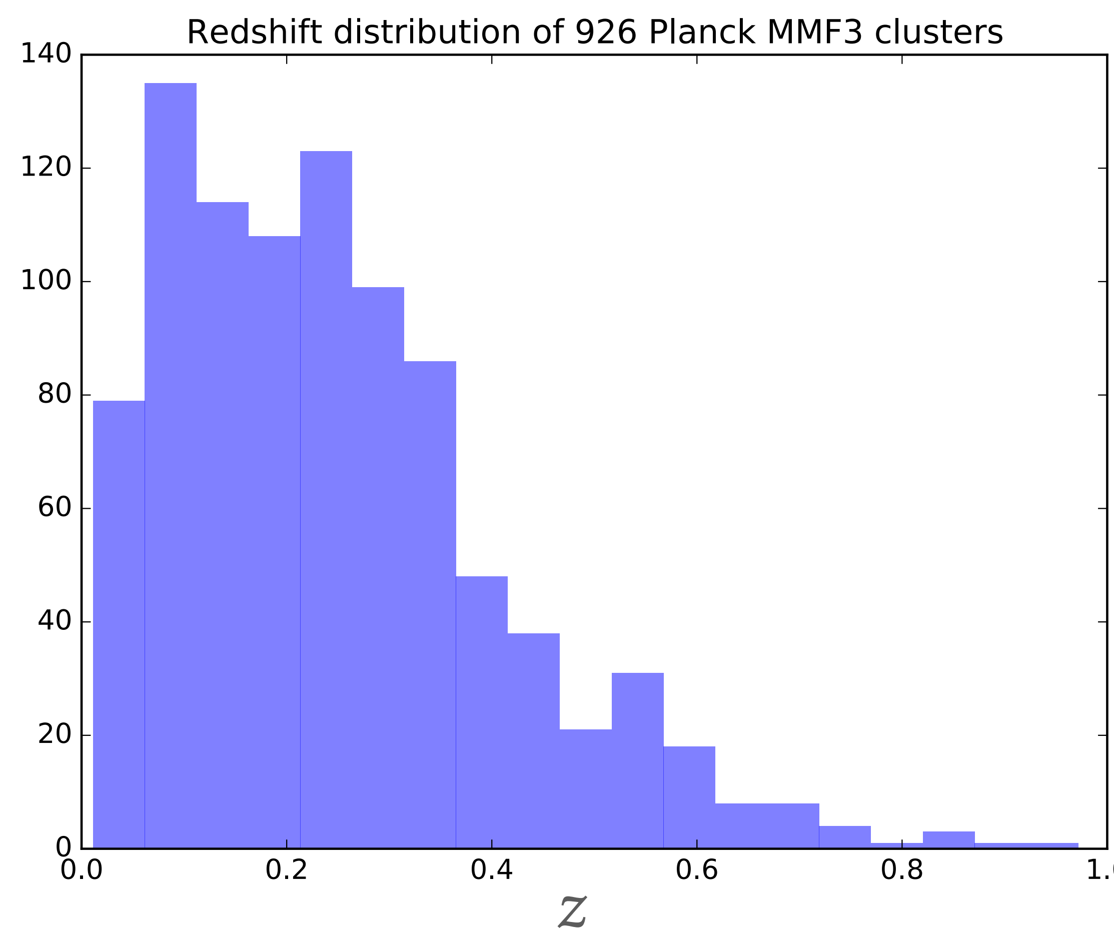
Multi-band observation of galaxy cluster Abell 2319 through CMB signal.

Distortion of CMB spectrum through SZ effect helps us to detect the galaxy cluster.

DATA: PLANCK SZ CLUSTER CATALOG

- Planck Sunyaev-Zel'dovich cluster catalog: **1271 clusters** from all sky-survey detected during 29 months (yellow dots), and the galactic mask (white area).
- **926 clusters** have redshift estimates.





ESTIMATOR OF TWO-POINT CORRELATION FUNCTION

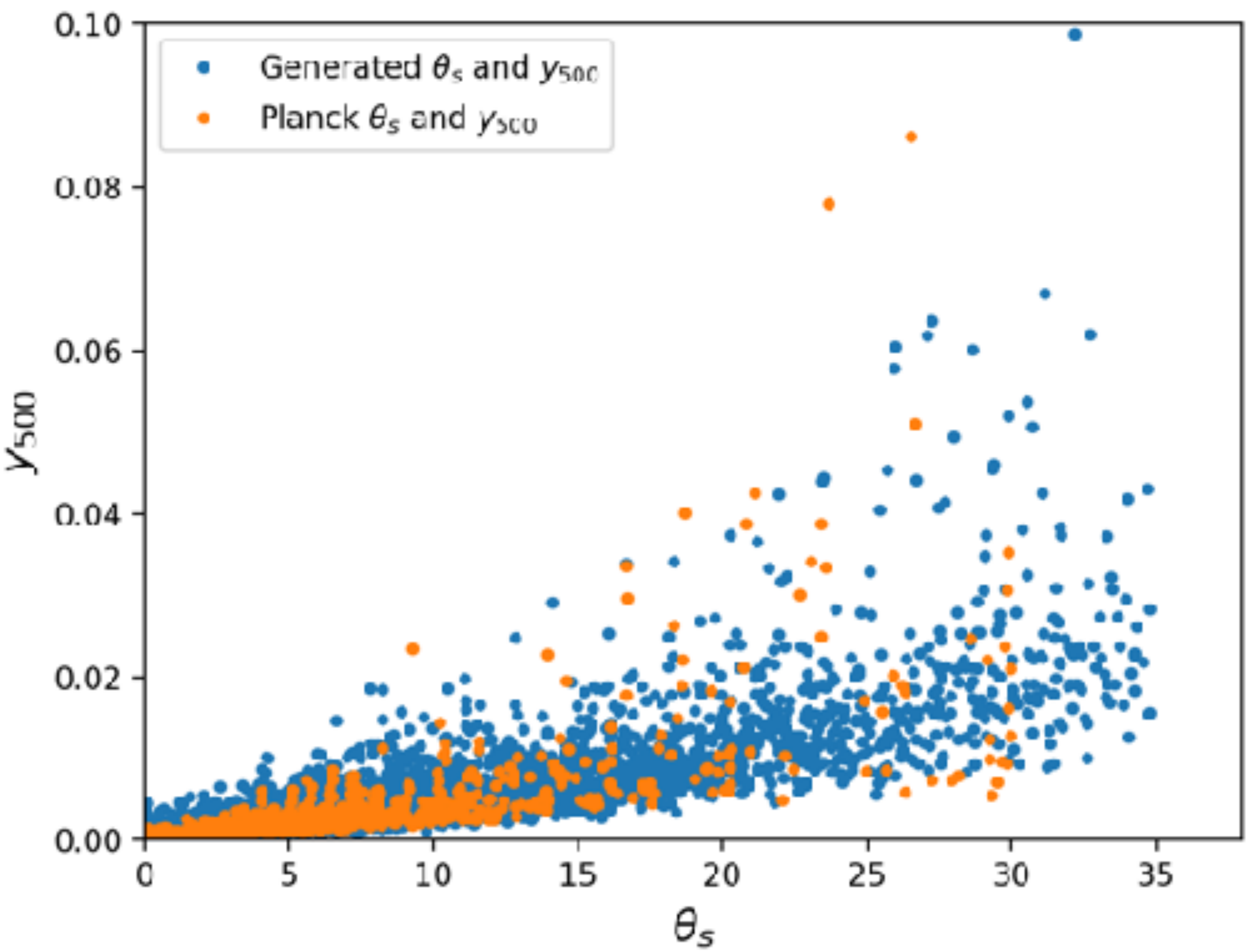
- Galaxy cluster is one of the probes of the large-scale structure of the universe.
- The two-point correlation function is a good statistical tool to quantify the **clustering** of sample.
- To measure the excess probability respect to the uniform distribution of finding a galaxy or a galaxy cluster in a sphere area $S(\theta)$ at an angular separation θ from another galaxy or galaxy cluster.
- It is important to produce the **random catalog** that has the same geometry effect of the mask and selection function as the data catalog.
- Landy and Szalay (1993): $\hat{w}_{LS}(\theta) = \dfrac{DD(\theta) - 2DR(\theta) + RR(\theta)}{RR(\theta)}$

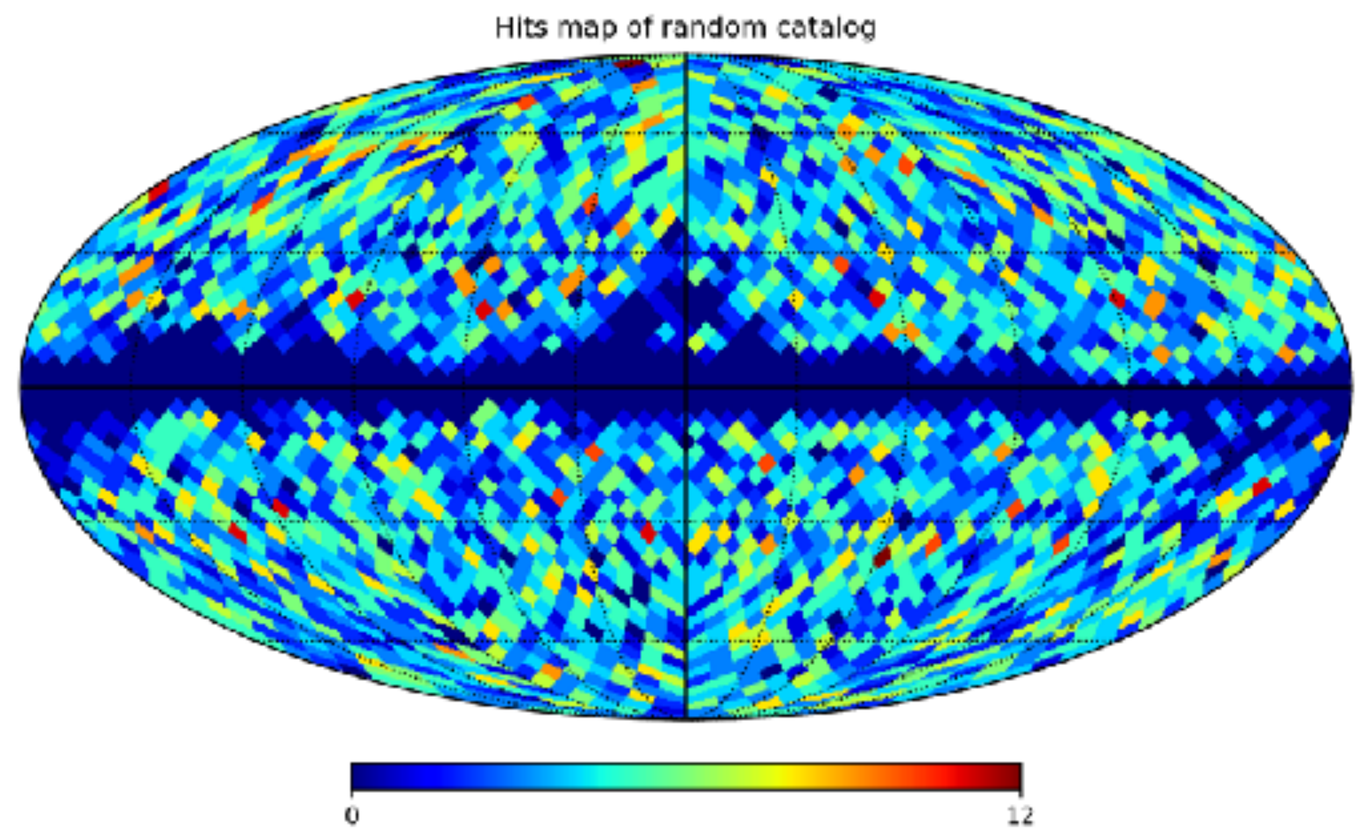
BUMP OF CORRELATION FUNCTION WITH RANDOM CATALOG?

- At the beginning of this work, we have created a random catalog as following:
  - Generate random clusters uniformly distributed position on the sky, angular size **ts500**, and flux **Y500**.
  - Apply Planck mask to the random catalog.
  - Apply selection function: each generated ts500 of random cluster corresponds to a map of sigma_y500 of the SZ flux (32 maps correspond to ts500 from 0.94 to 35.32 arcmin)
  - Keep clusters have generated $y > 4 * \sigma_{y500}$

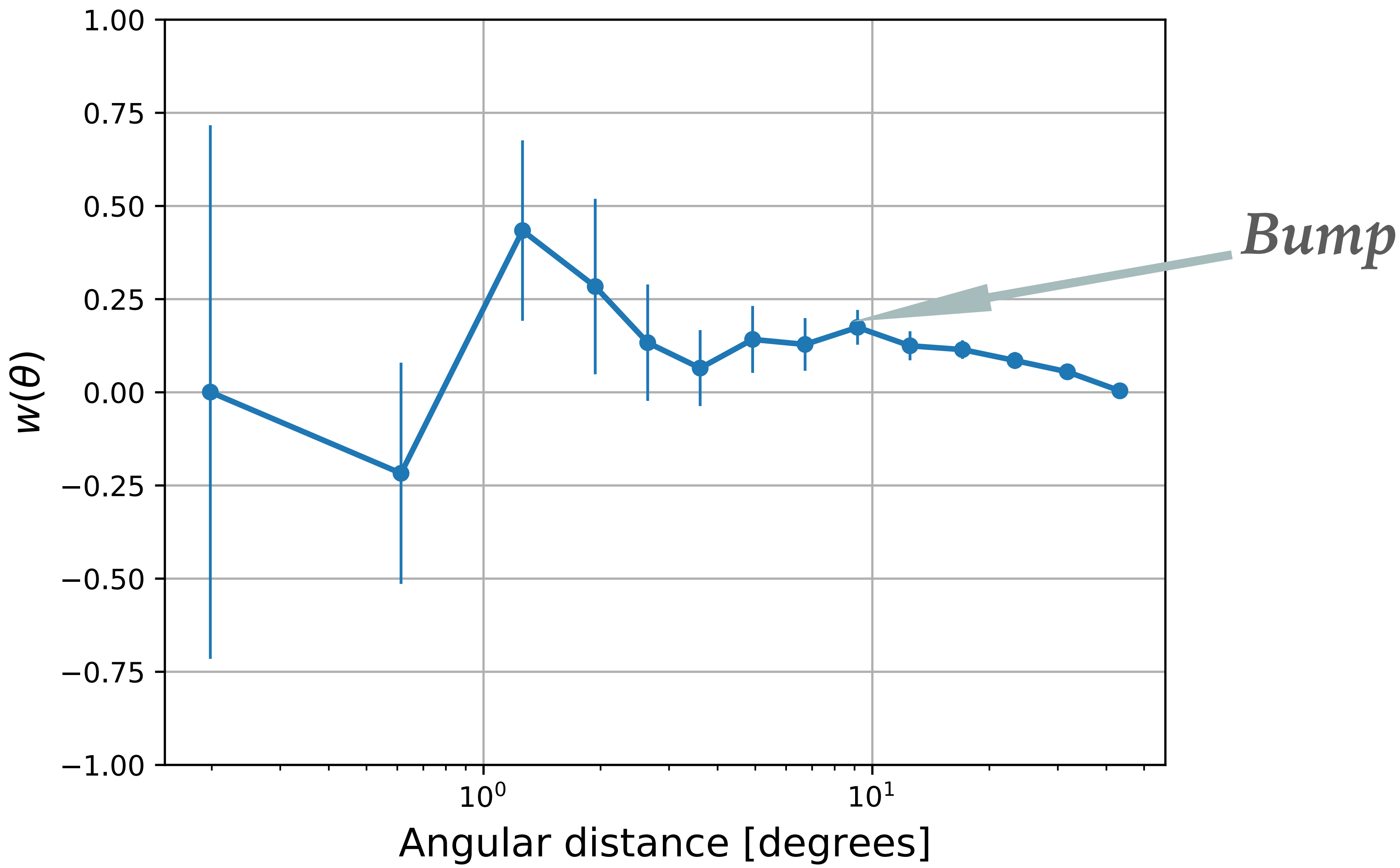
BUMP OF CORRELATION FUNCTION WITH RANDOM CATALOG?

First Result





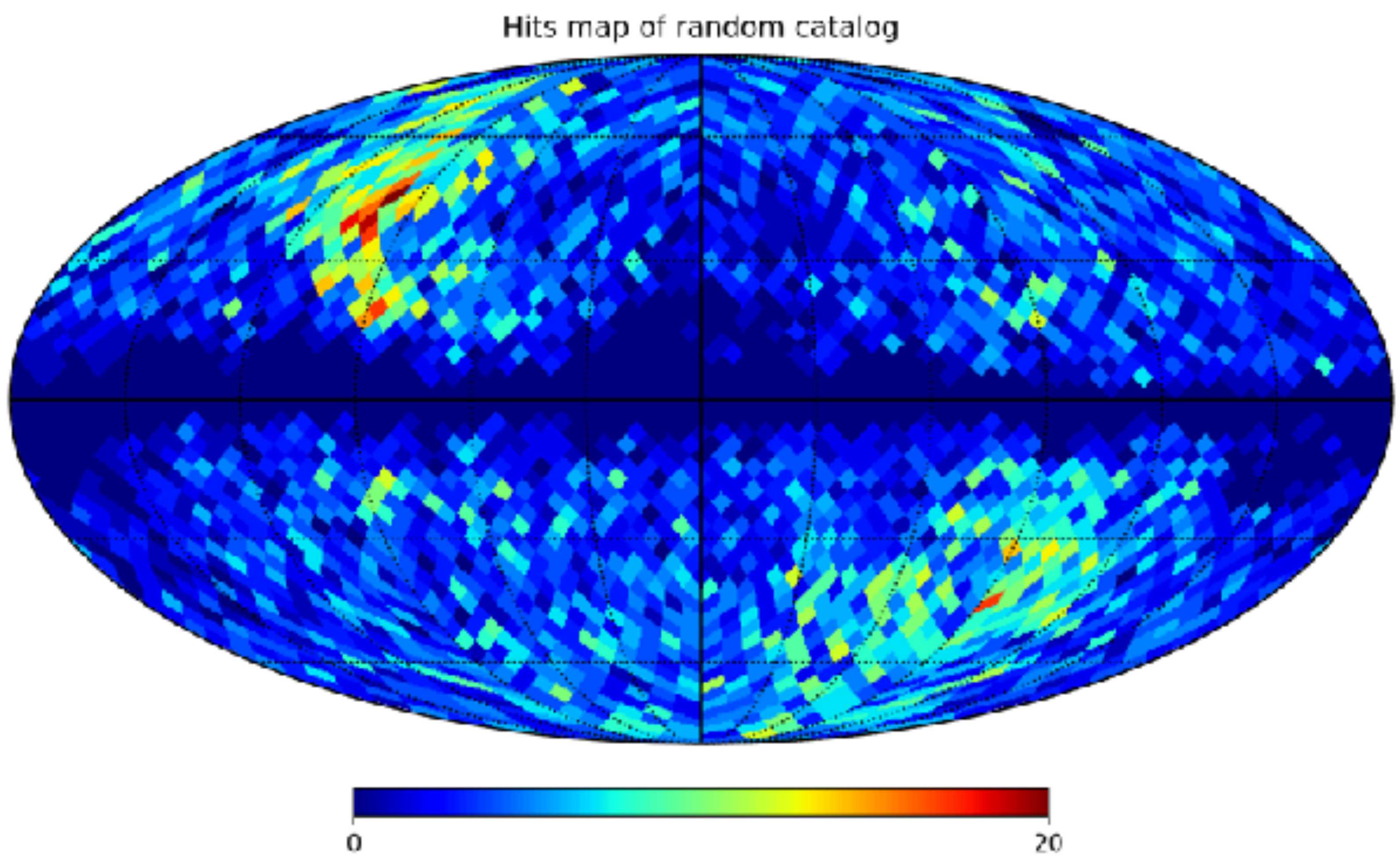
BUMP OF CORRELATION FUNCTION WITH RANDOM CATALOG?



- We can see the bump at angular distance ~10 degrees.
- We thought that it could be a Baryonic Acoustic Oscillation (BAO) peak.
- However, this bump is actually an artefact due to the 10x10 square degrees patches of the selection function of Planck clusters. [arXiv:1501.02840v1]

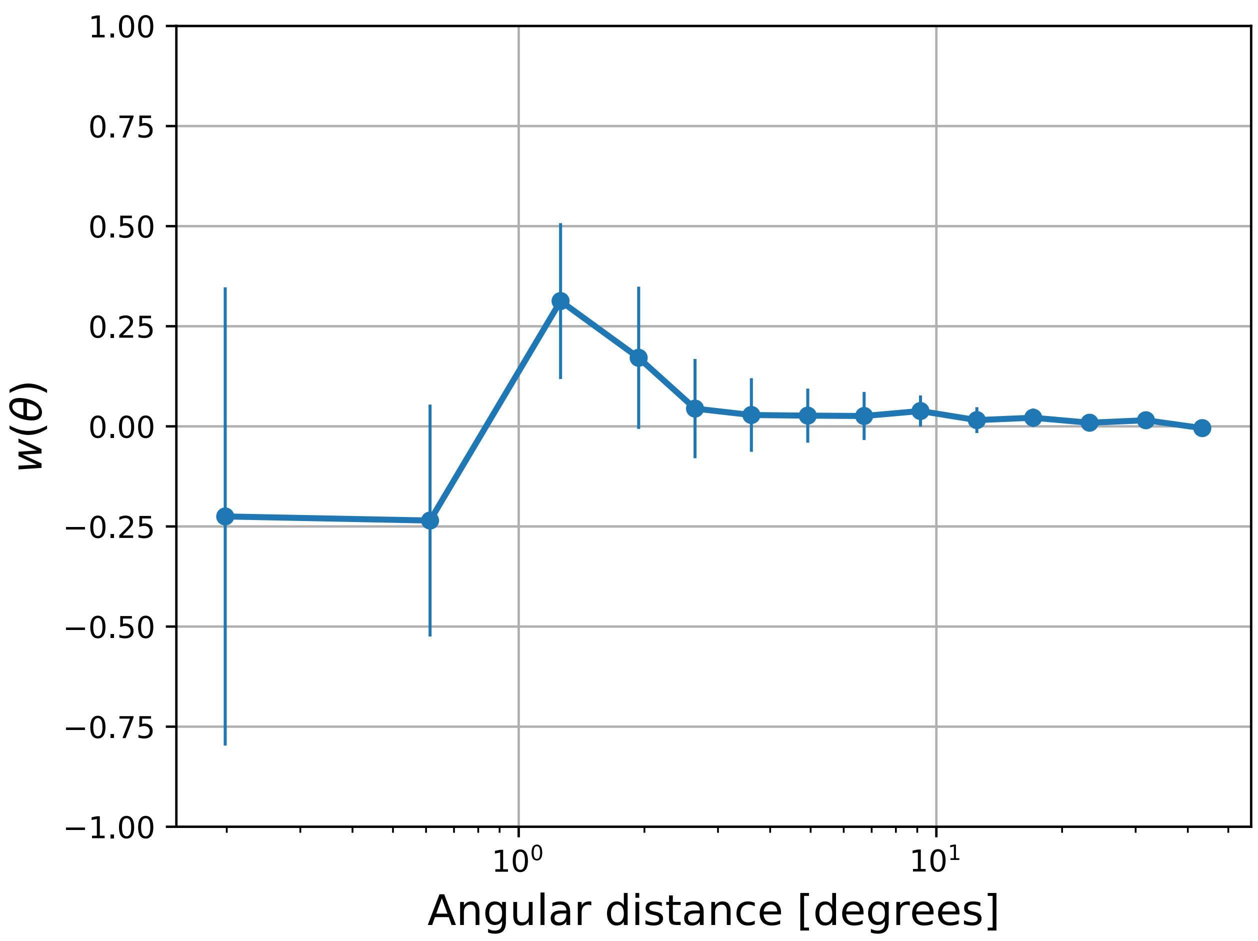
IMPROVED SIMULATION OF RANDOM CLUSTER CATALOG

- The catalog is generated as a random draw from the Planck 2015 baseline SZ cosmological model and scaling relations between (Y500, ts500) and (mass, redshift).
- Both the mask and selection function have been applied



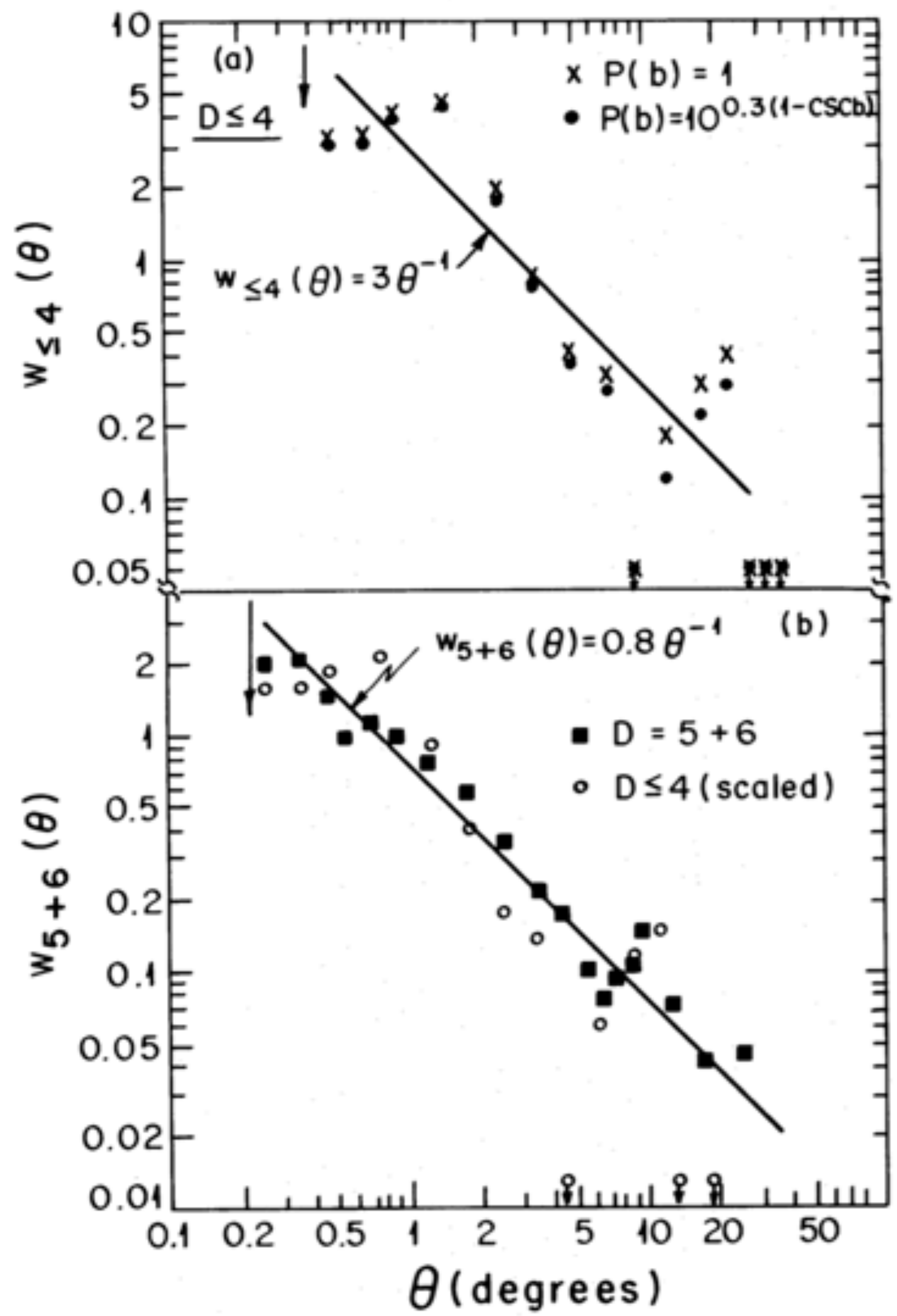
RESULTS

- The bump at 10 degrees disappears.
- Error bars are estimated by bootstrap method.
- Anti-correlation at angular distance <1 degrees.
- High correlation at angular distance from 1 to 3 degrees.
- Positive and lower clustering at higher angular distance.



COMPARE WITH ABELL CLUSTER CATALOG

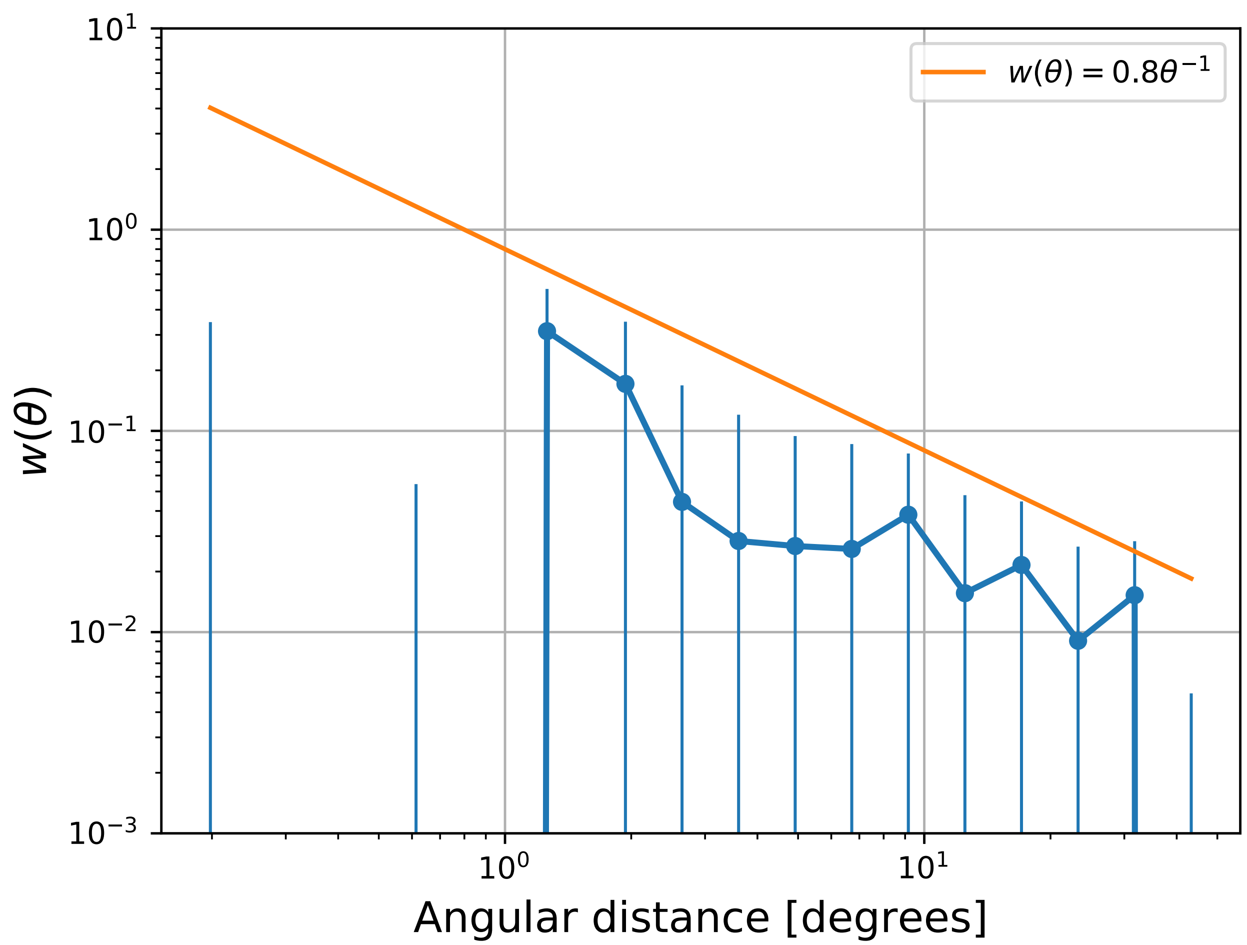
- Abell cluster catalog(Abell 1958): a rich cluster catalog, ground observation, is located at high galactic latitude b>= 30^{o}, no full redshifts estimates.
- Bahcall and Soneira (1982) used this catalog:
  - Distance class D ≤ 4 sample of 104 clusters (z<0.1, one cluster no redshift)
  - D=5+6 sample of 1547 clusters (z<0.2, only few clusters have redshifts).
- They found the power law of correlation for D=5+6 sample: $w(\theta) = 0.8\theta^{-1}$



Bahcall & Soneira 1982

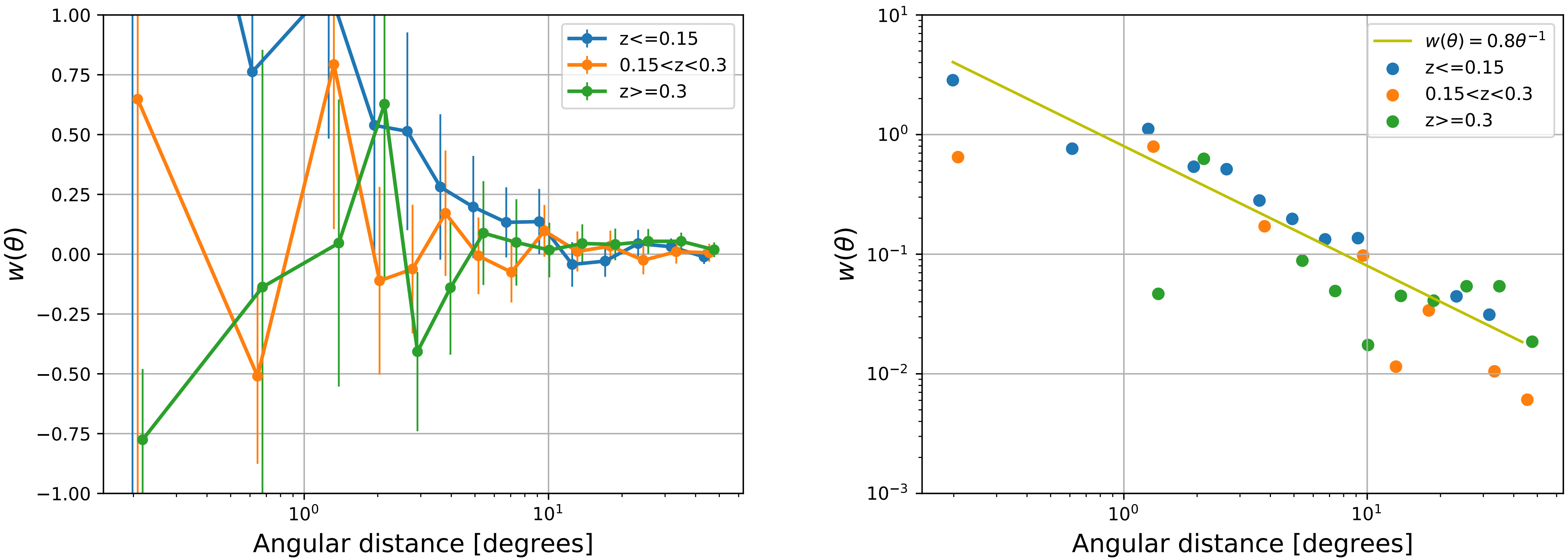
COMPARE WITH BAHCALL AND SONEIRA (1982)

- Correlation of Planck SZ cluster catalog is lower than Abell clusters (orange line), because:
  - Because the number of Planck clusters is smaller than Abell's.
  - The range of redshifts of Planck is wider, with z up to 1.
  - Planck survey is all over sky.



TWO-POINT CORRELATION AT DIFFERENT REDSHIFTS

➤ Divide the Planck clusters into 3 redshift groups: z <= 0.15 (296 clusters); 0.15 < z < 0.3 (330 clusters) and z >= 0.3 (300 clusters).



➤ Strong clustering for lowest redshift group (z<=0.15) and it fits quite well the power law of Bahcall and Soneira.

CONCLUSIONS

- No typical signal for clustering signal because of large uncertainty.
- Different redshift cluster groups give us different correlation of clusters. Smallest redshift cluster group fits the power law of Bahcall et Soneira (1982).
- Error bars are large may due to low number of clusters.
- Selection function of Planck causes the bump of the correlation function of Planck when using a simple random catalog.
- Future missions will observe more cluster data:
  - COrE: 52000 clusters with S/N ≥5 in which 500 clusters with z>1.5 [arXiv:1703.10456]. But it was not selected by ESA for M5 mission for a launch in 2030.
  - Euclid will find about **60000 clusters** with S/N > 3 and redshifts ***z from 0.2 to 2***. [Laureijs et al. 2011, Euclid Definition Study Report]. (Take image of **1.5 billion galaxies** and **35 million** spectroscopic redshifts).

THANK YOU FOR YOUR ATTENTION!