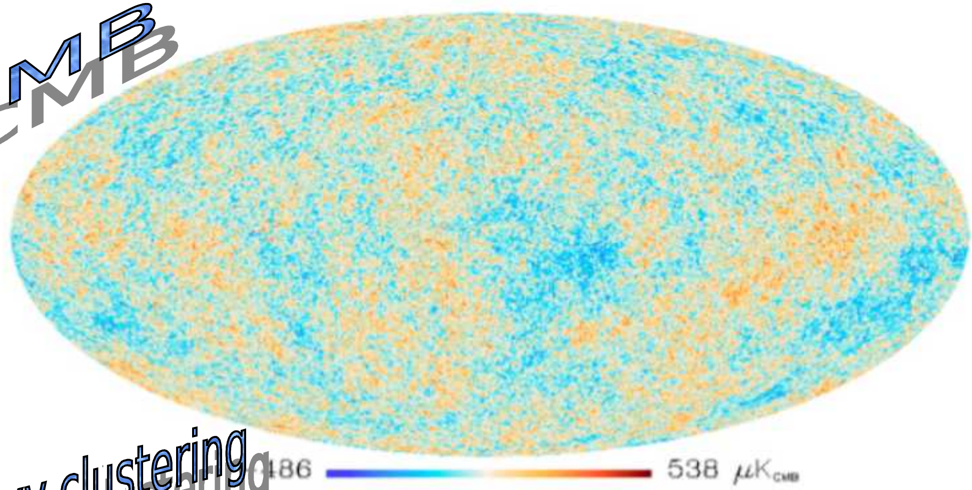
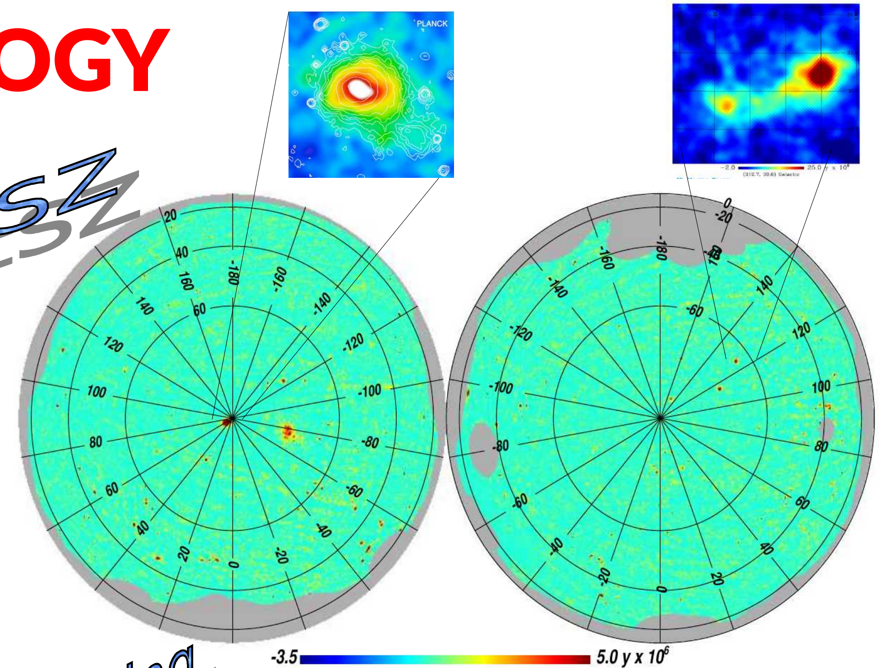
OBSERVATIONAL COSMOLOGY

J.F. Macías-Pérez

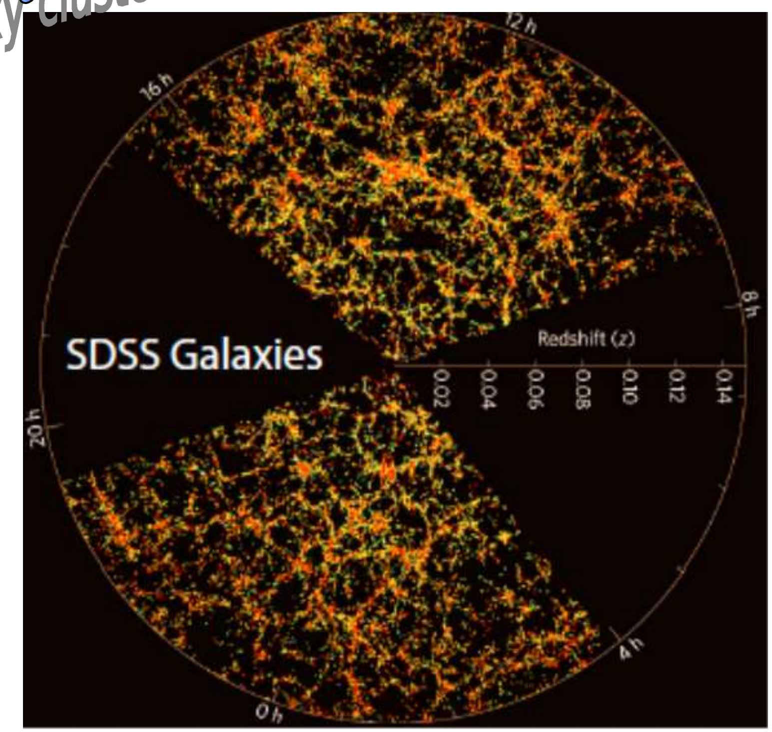
CMB



tSZ

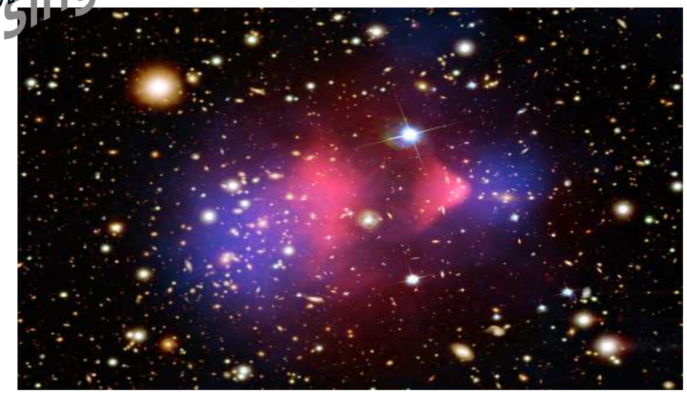


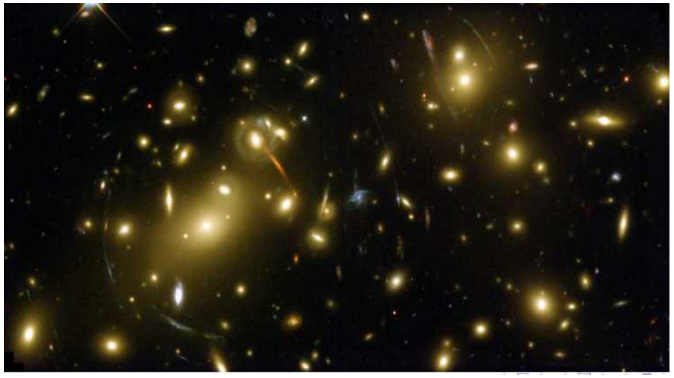
Galaxy clustering



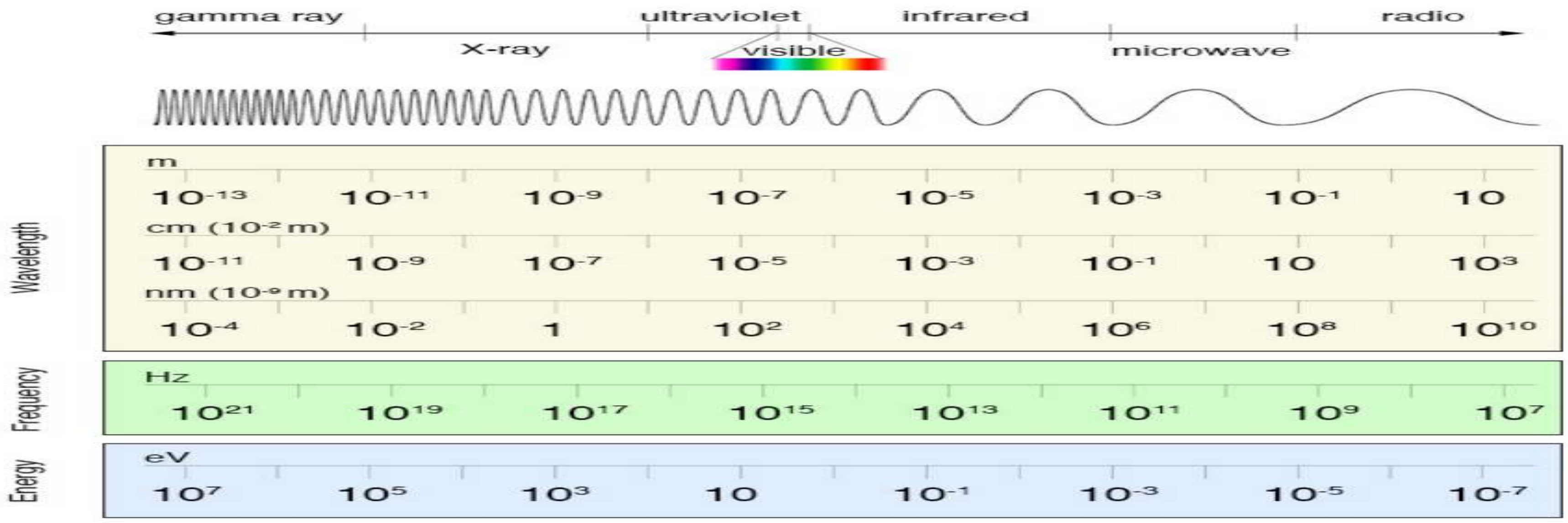
EXPERIMENTS

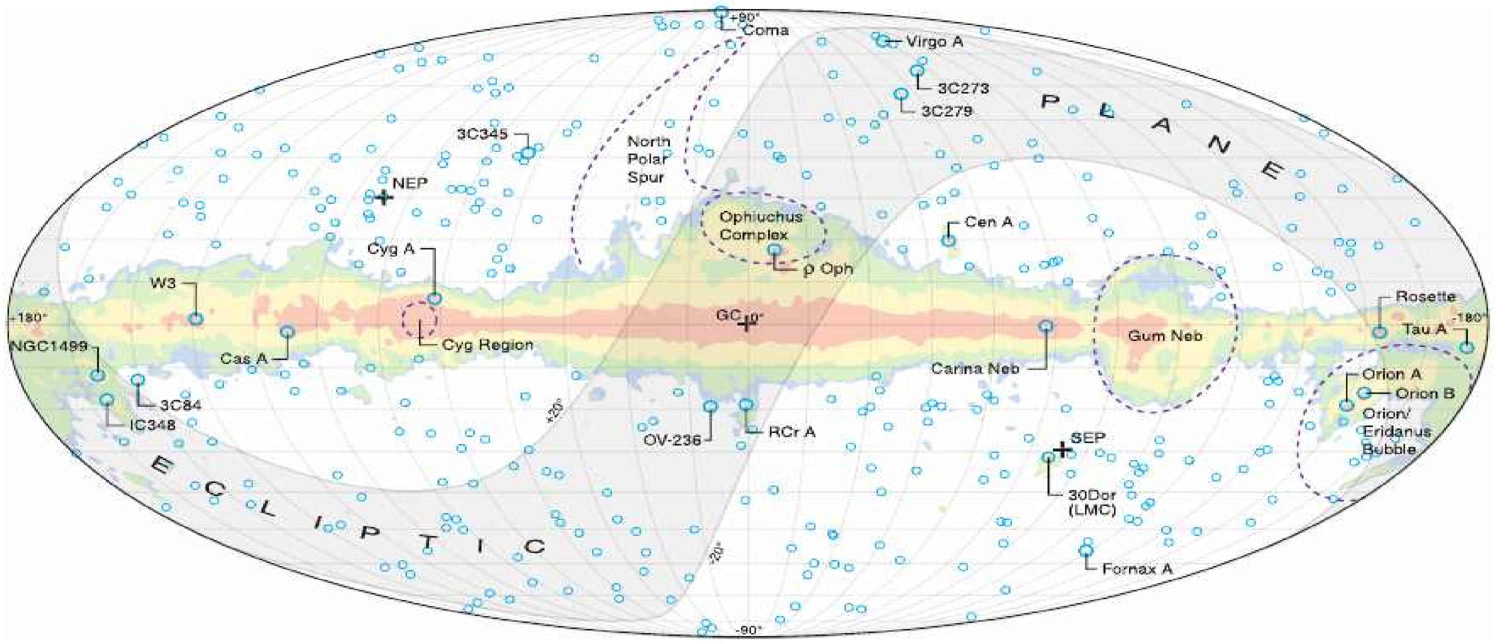
lensing



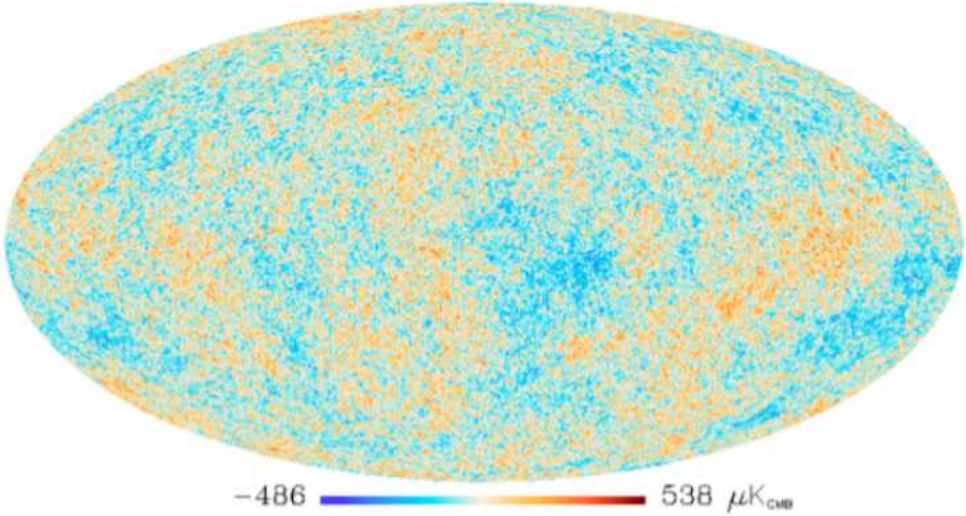


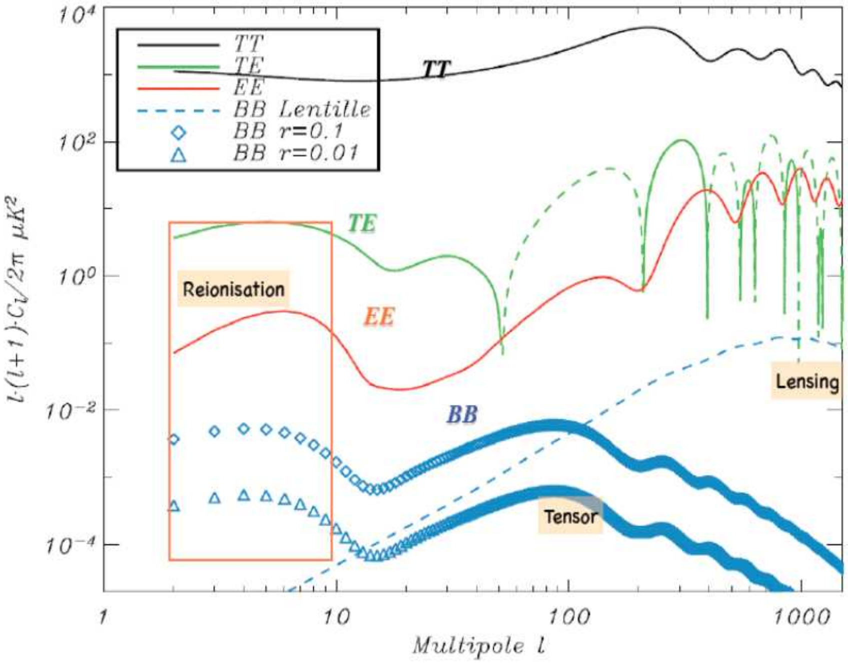
Observing the sky

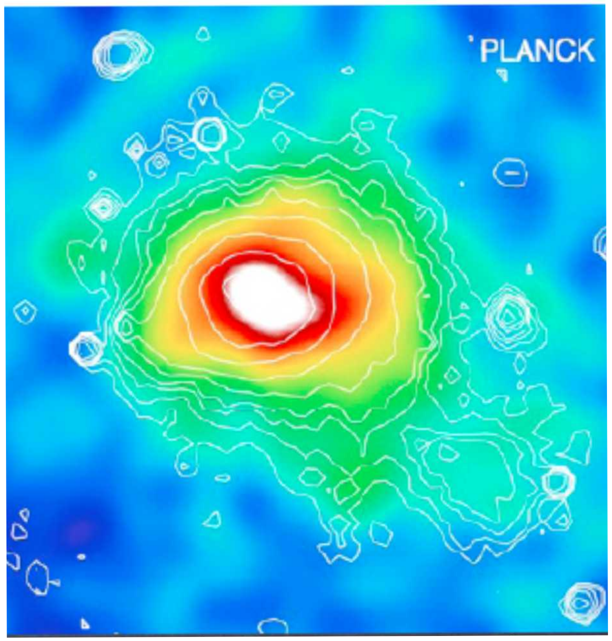




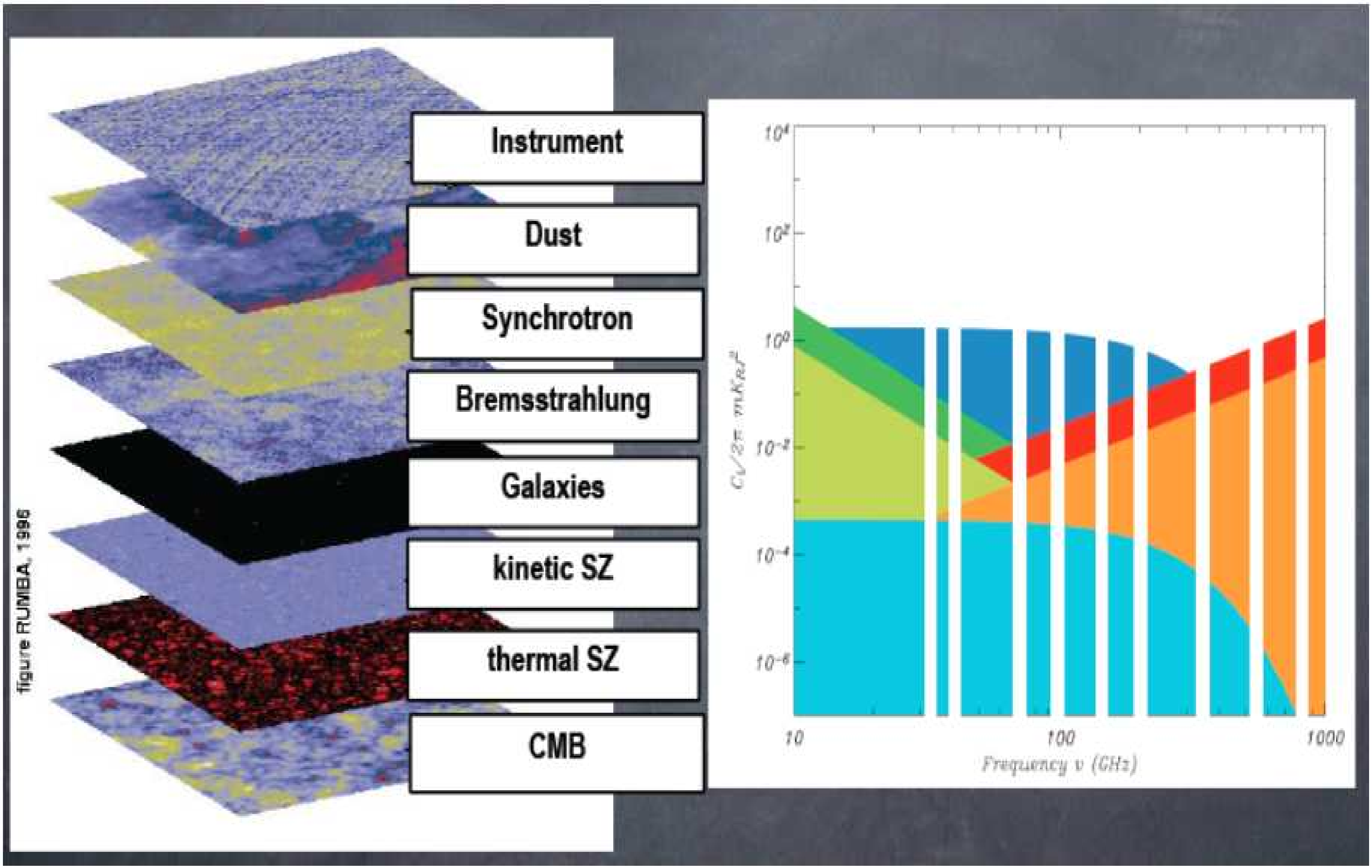
Part I :
CMB OBSERVATIONS



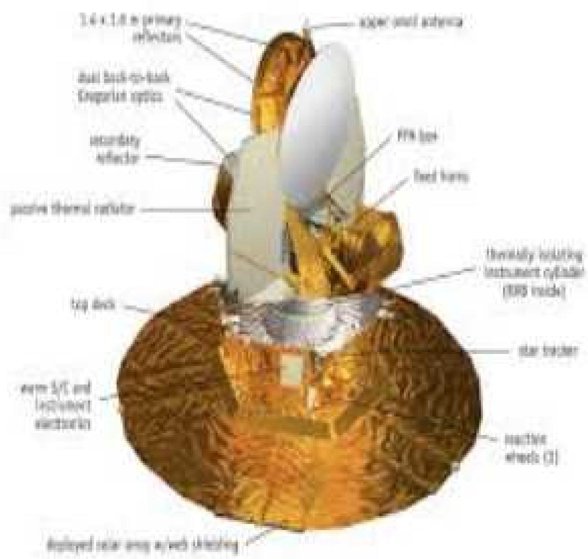


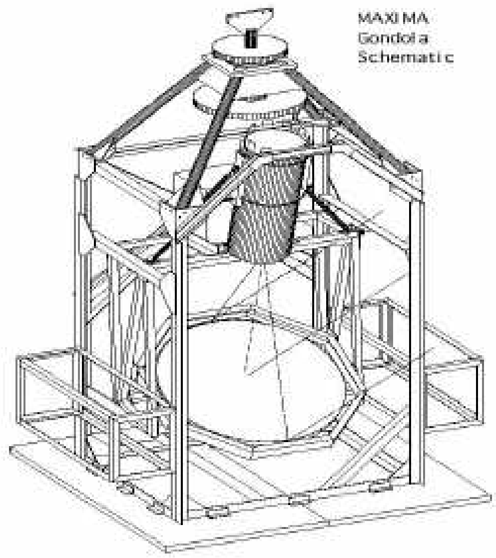


Observing the « CMB » sky



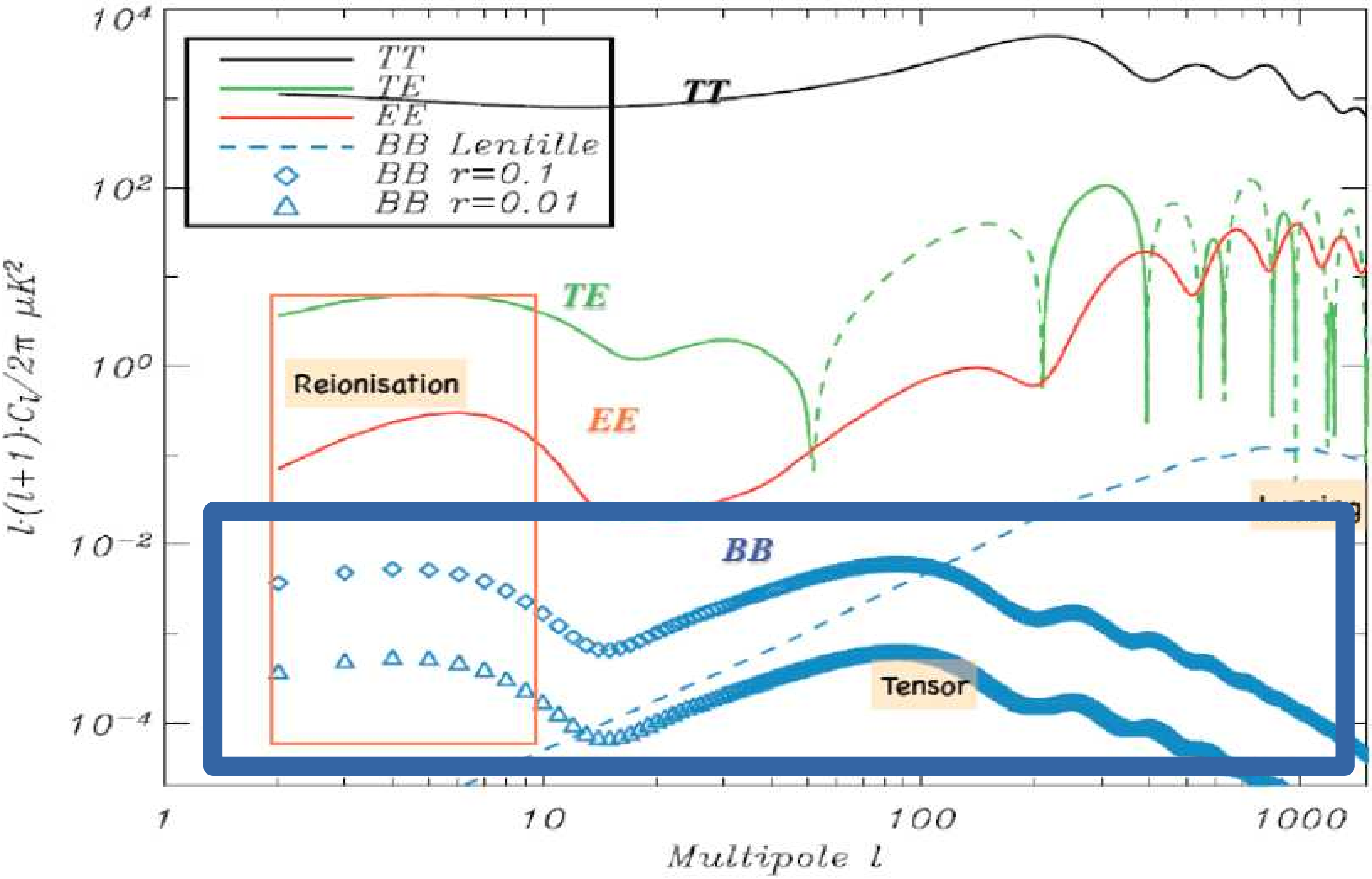
CMB experiments





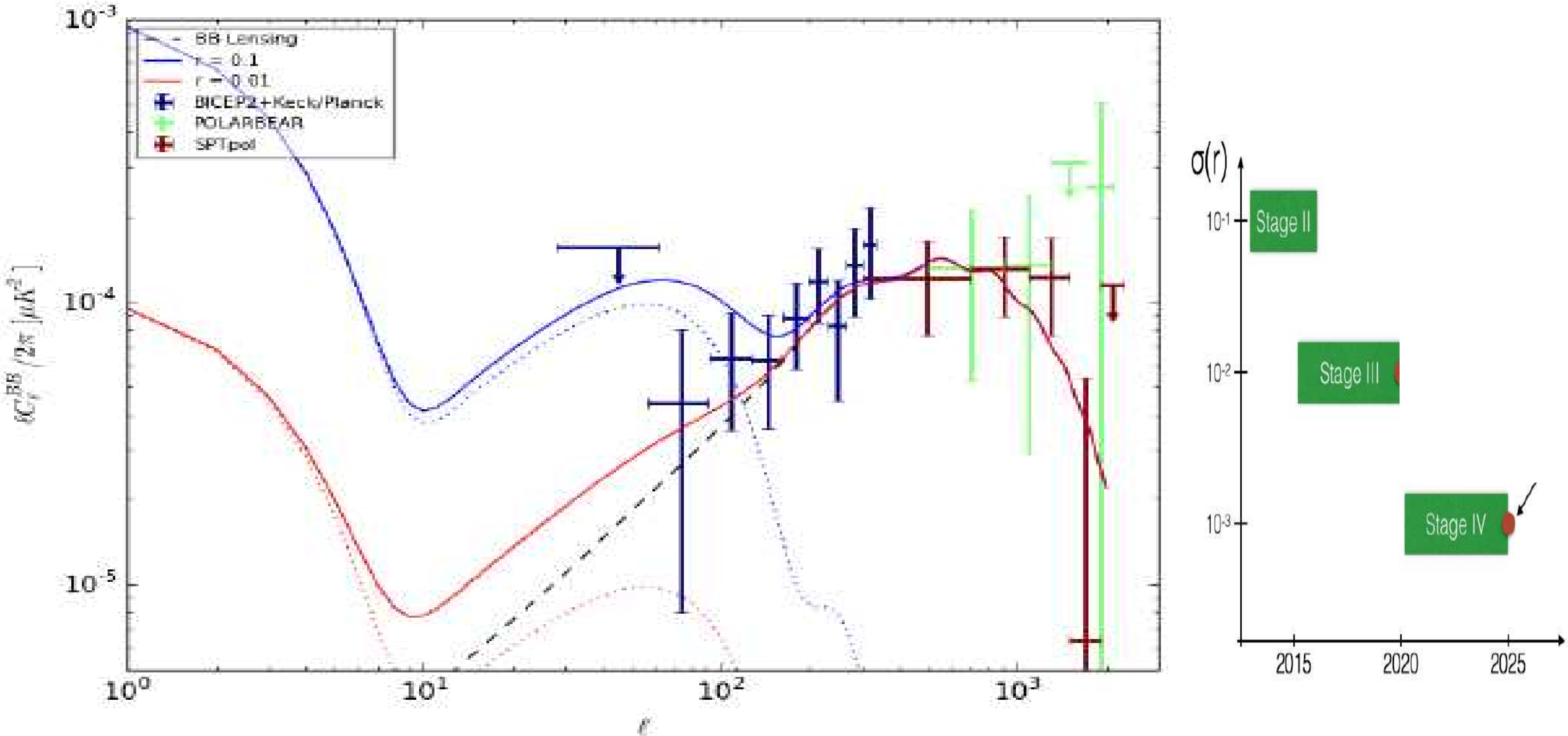
	Radio	mm
Telescopes	dish and horns	dish and horns
Detectors	HEMT + square law detectors	bolometer and/or KIDs
Cooling	18-50 K	100-300 mK
Observing mode	Ground, satellite	ground, balloon, satellite

CMB intensity and polarisation power spectra : the quest for B-modes



CMB B-modes measures the tensor-to-scalar ratio, r, which is directly related to inflation energy scale

CMB intensity and polarisation power spectra : the quest for B-modes



Current results are limited by foreground contamination, r<0.07 @ 95 % C.L. [BICEP, KECK & Planck]

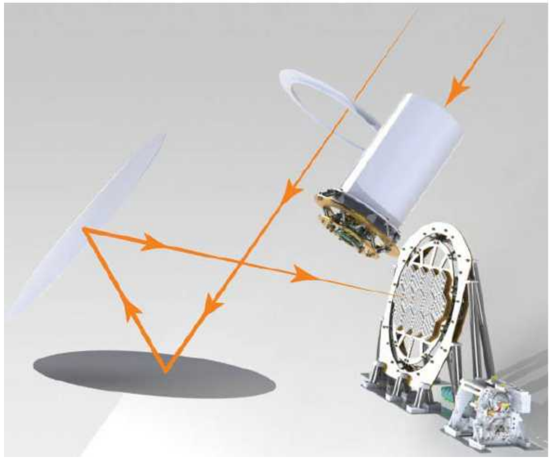
« Some » current (planned) CMB experiments

Project	Country	Location	Status	Frequencies (GHz)	ℓ range value	Ref.	$\sigma(r)$ goal no fg.	with fg.
QUBIC	France	Argentina		150,220	30-200		0.006	0.01
Bicep3/Keck	U.S.A.	Antartica	Running	95, 150, 220[1]	50-250	[22]	$2.5\ 10^{-3}$	0.013
CLASS	U.S.A.	Atacama	≥ 2016	38, 93, 148, 217	2-100	[29]	$1.4\ 10^{-3}$	0.003
SPT3G	U.S.A.	Antartica	2017	95, 148, 223	50-3000	[23]	$1.7\ 10^{-3}$	0.005
AdvACT	U.S.A.	Atacama	Starting	90, 150, 230	60-3000	[24]	$1.3\ 10^{-3}$	0.004
Simons Array	U.S.A.	Atacama	≥ 2017	90, 150, 220	30-3000	[25]	$1.6\ 10^{-3}$	0.005
LSPE	Italy	Artic	2017	43, 90, 140, 220, 245	3-150	[30]	0.03*	
EBEX10K	U.S.A.	Antartica	≥ 2017	150, 220, 280, 350	20-2000	[28]	$2.7\ 10^{-3}$	0.007
SPIDER	U.S.A.	Antartica	Running	90, 150	20-500	[26]	$3.1\ 10^{-3}$	0.012
PIPER	U.S.A.	Multiple	≥ 2016	200, 270, 350, 600	2-300	[27]	$3.8\ 10^{-3}$	0.008

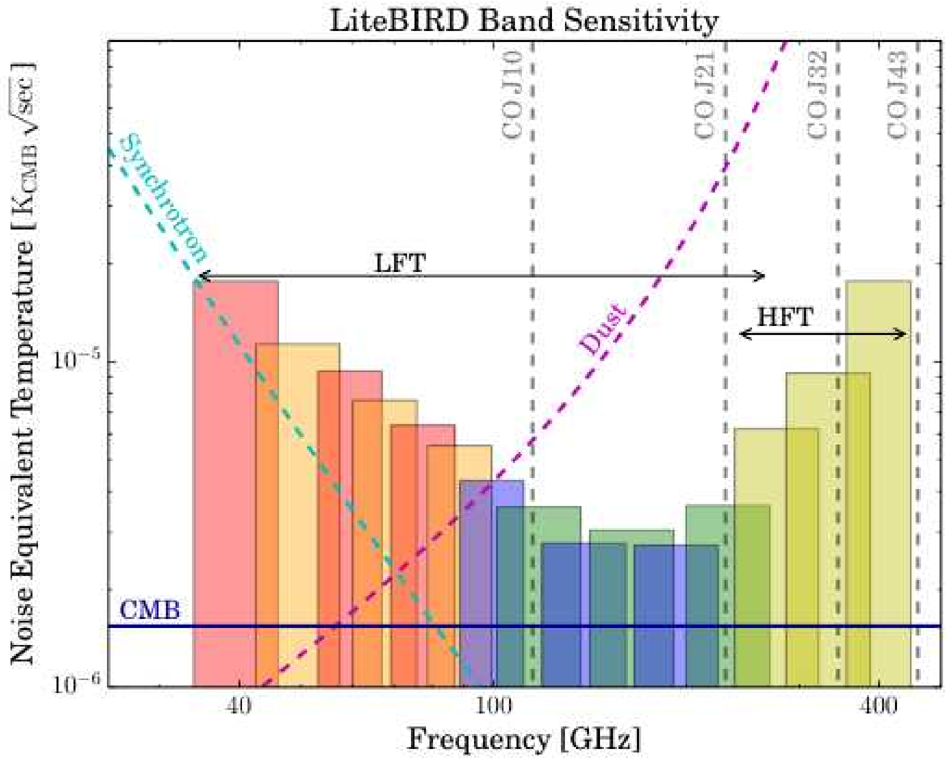
+ proposed satellites : LITEBIRD (2028), PRISTINE (?), CORE (2035?)
+ ground S4 (2030 ?)

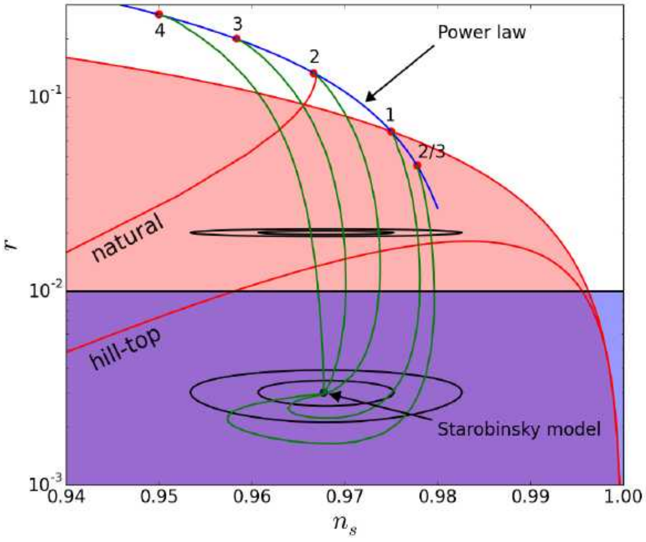
LITEBIRD satellite

LITEBIRD design and expected performance



- Multi-band instrument, 15 frequency bands from 40 to 400 GHz
- Two independent telescopes : LFT (40-135 GHz ; 12 bands) and HFT (250-400 GHz, 3 bands)
- Resolution 20’ to 70’
- Cold continuosly rotating Half-wave-plate
- 2622 TES cooled down @ 0.1
- 2 years of operation
- Launch expected for 2026-2027
- Japanese + USA collaboration, European (French) contributions (phase A)





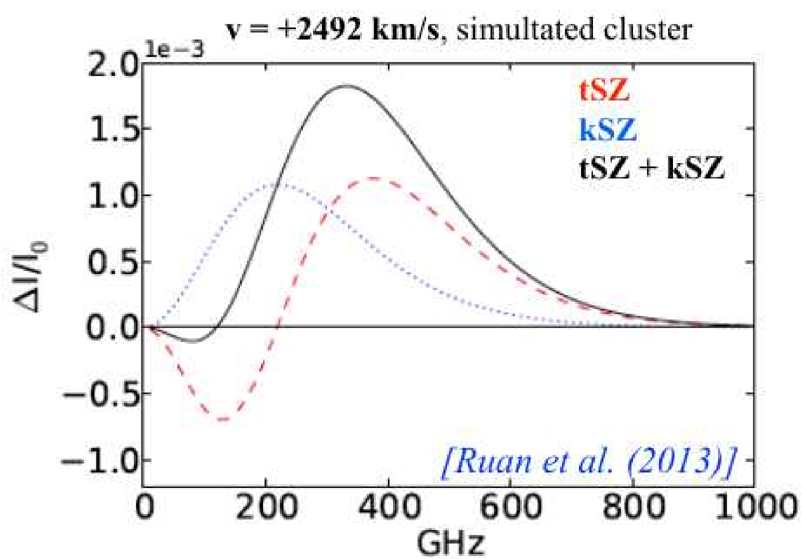
10^{-3} sensitivity in r in 2 years of operation, good foreground removal, problems with delensing

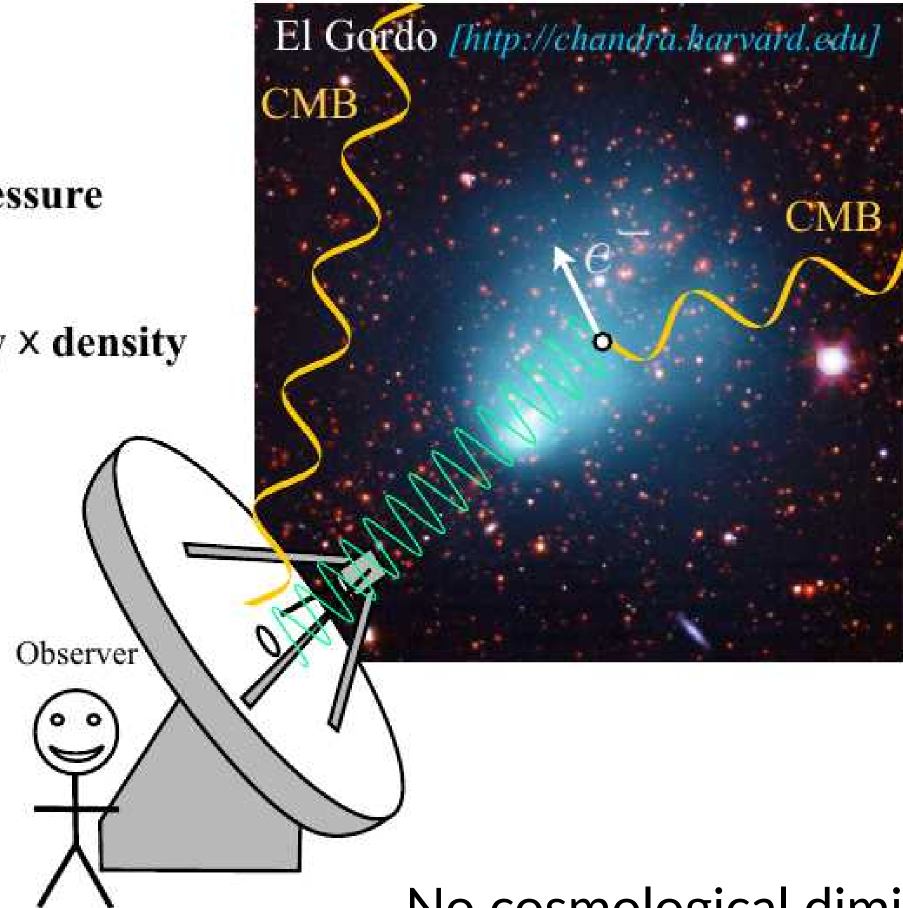
Sunyaev-Zeldovich effect

- **tSZ** = CMB spectral distortion from interaction with clusters' hot electrons
- **kSZ** = CMB Doppler shift from bulk motion of electrons (typically ~ tSZ/10)

$$\frac{\Delta I_\nu}{I_0} = f_\nu \; y_{\mathrm{tSZ}} + g_\nu \; y_{\mathrm{kSZ}}$$

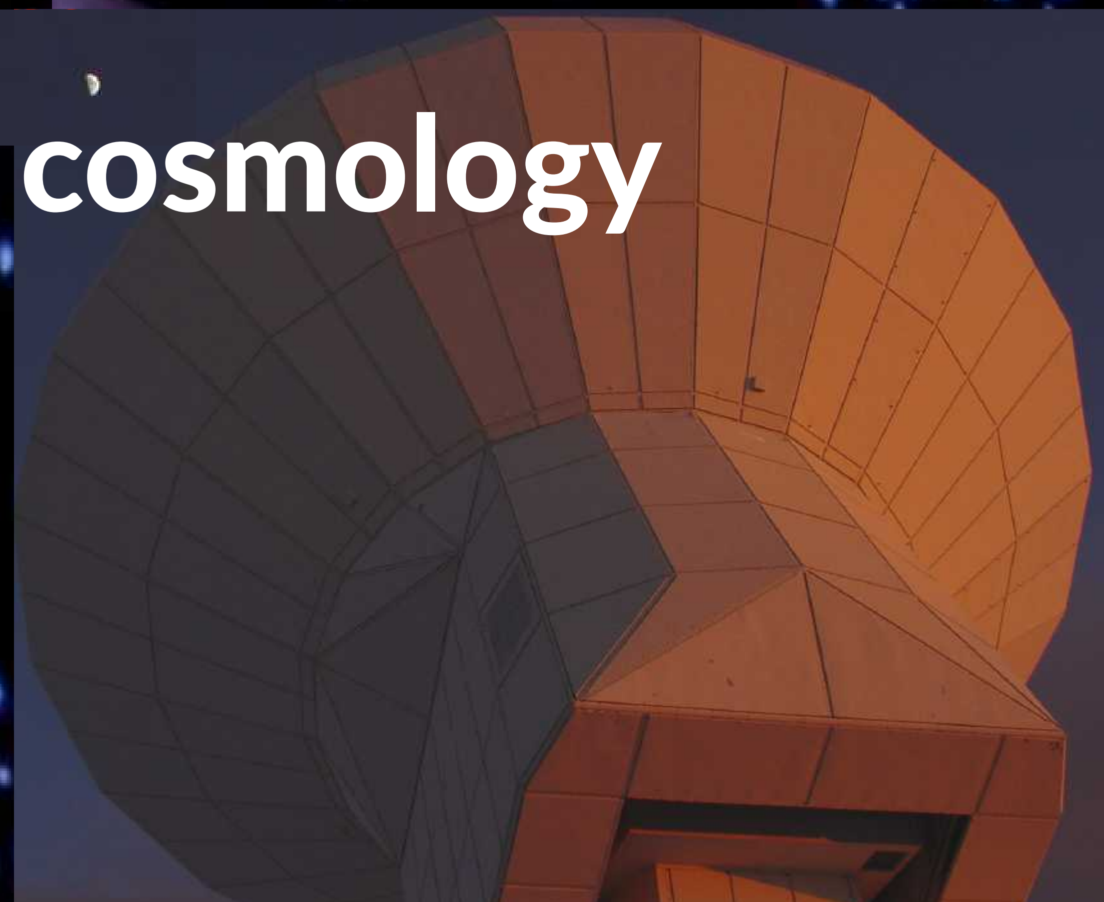
$$\begin{cases} y_{\mathrm{tSZ}} = \dfrac{\sigma_{\mathrm{T}}}{m_e c^2} \displaystyle\int P_e \, d\ell & \Rightarrow \textbf{Pressure} \\ y_{\mathrm{kSZ}} = \sigma_{\mathrm{T}} \displaystyle\int \dfrac{-v_z}{c} n_e \, d\ell & \Rightarrow \textbf{Velocity × density} \end{cases}$$





No cosmological diming

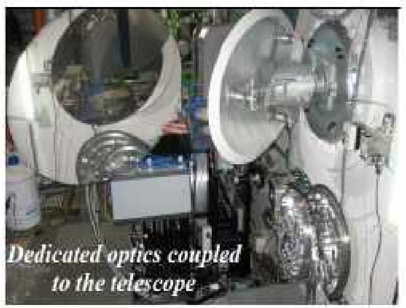
➡ **SZ = probe for intracluster gas**



NIKA2: a millimeter camera for cluster cosmology

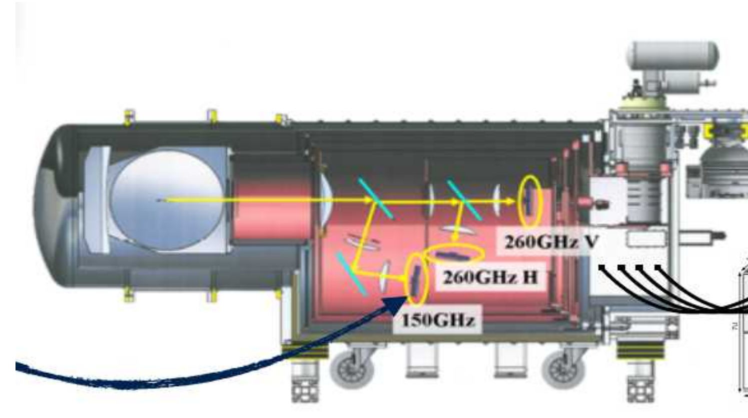
Dual band mm KID camera operating and 150 and 260 GHz

IRAM 30-m telescope
at Pico Veleta (Spain)



Specific optical system to
obtain the largest FOV

Dilution cryostat:
180 mK nominal
temperature



Arrays of 1140 (616) KIDs:
8 (4) independent feedlines
with up to 200 KID each

300 multiplexing factor

20 boxes (one per feedline)
arranged in 3 crates (one per
array)

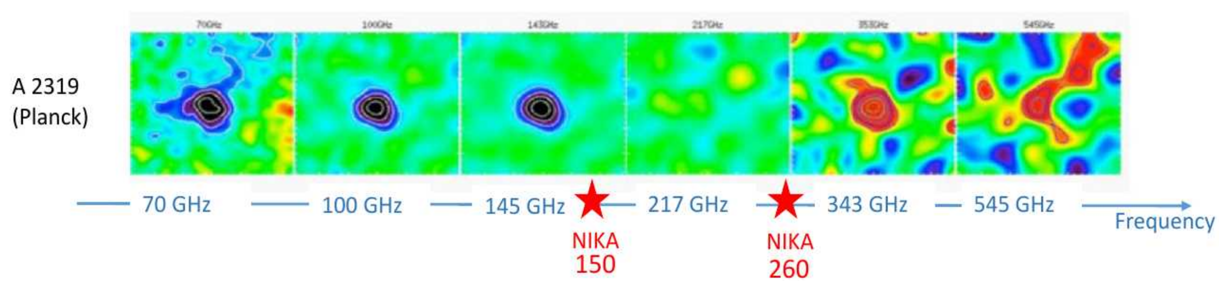
NIKA2

- September 2015 : installation at IRAM
- October 2015 : First lights
- September 2016 : complete instrumental setup
- April 2017 : commissioning succesfully finished ; performance better than expected
- Open to for public observations for at least one decade from now

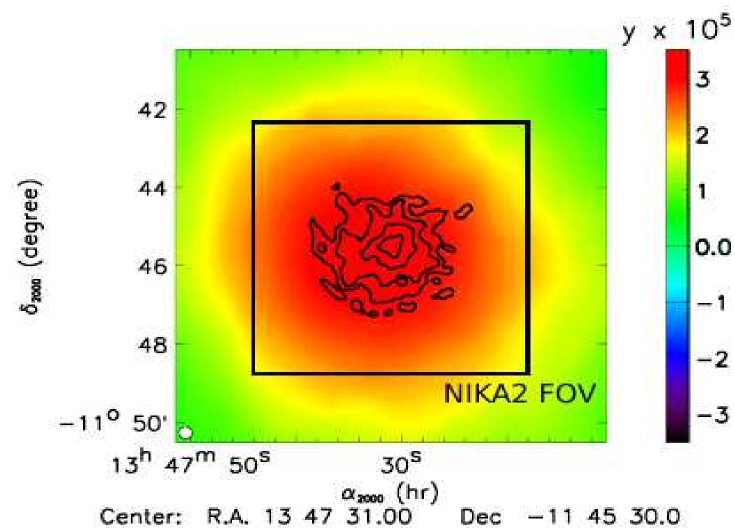
Frequency	150 GHz	260 GHz
# KIDs	616 (553)	2 x 1140 (960)
FOV diameter	6.5 arcmin	6.5 arcmin
Sensitivity	9 $mJy/s^{1/2}$	33 $mJy/s^{1/2}$
Angular res.	17.7 arcsec	11.2 arcsec

[NIKA collaboration, A&A, 2017,arXv:]

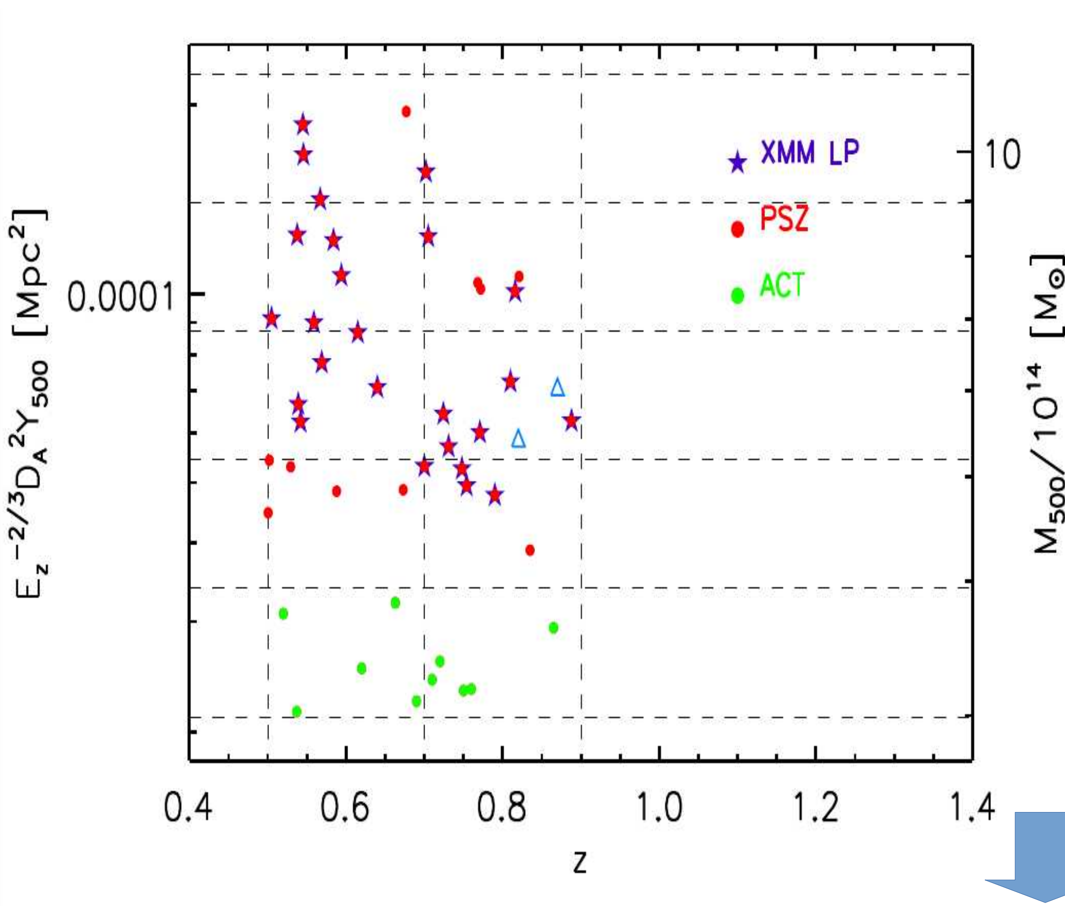
NIKA2 is well adapted for SZ observations of intermediate and high redshift



- Two frequency bands, negative & zero tSZ signal
- Large FOV : size of PLANCK beam
- High resolution : 17 times better than Planck



NIKA2



One of the 5 NIKA2 LP (1300h in total)

- **300 hours** of tSZ observation
- **50 high redshift clusters 0.5 < z < 1.0**
- tSZ selected clusters from Planck and ACT catalogues

Ancillary data

- X-ray follow-up with XMM
- Optical data using GranTeCan
- MUSIC hydrodynamic simulations

Main goals

- In-depth study of ICM
- Thermodynamic properties: pressure, density, temperature and entropy profiles
- Mass – tSZ flux relationship

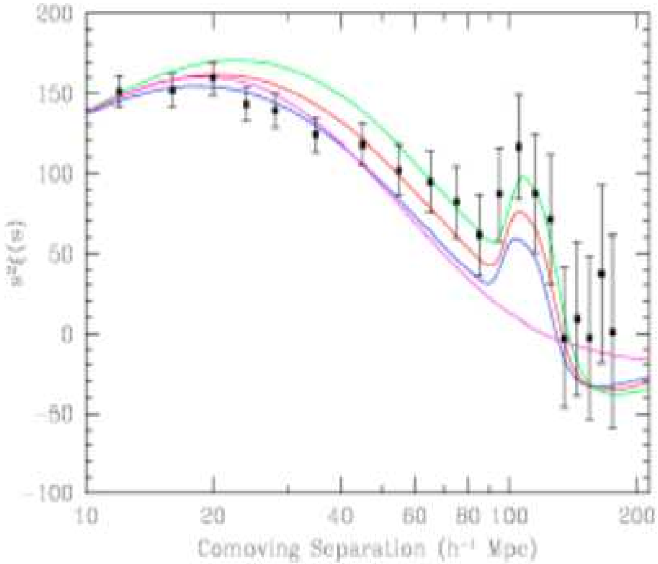
Redshift evolution of:

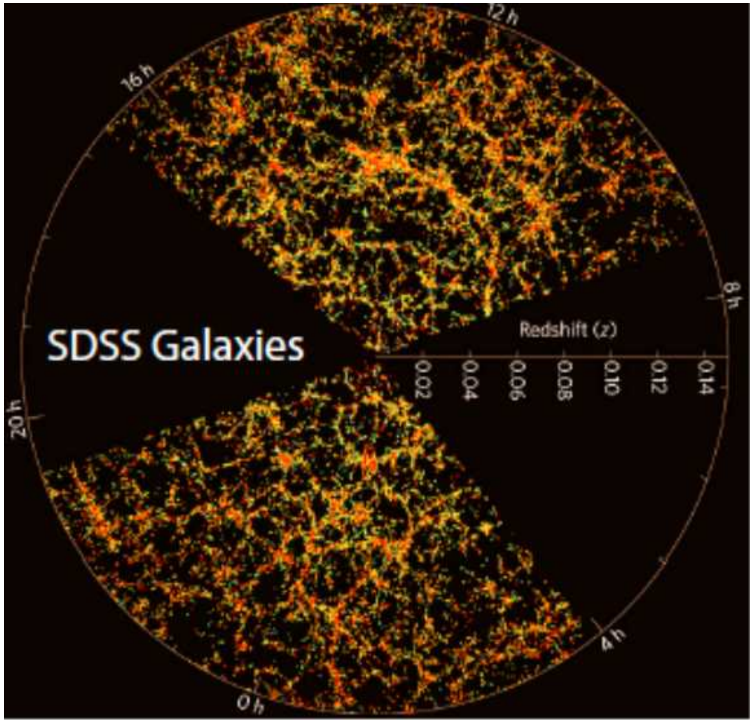
- Thermodynamic quantities profiles
- Scaling laws and hydrostatic bias

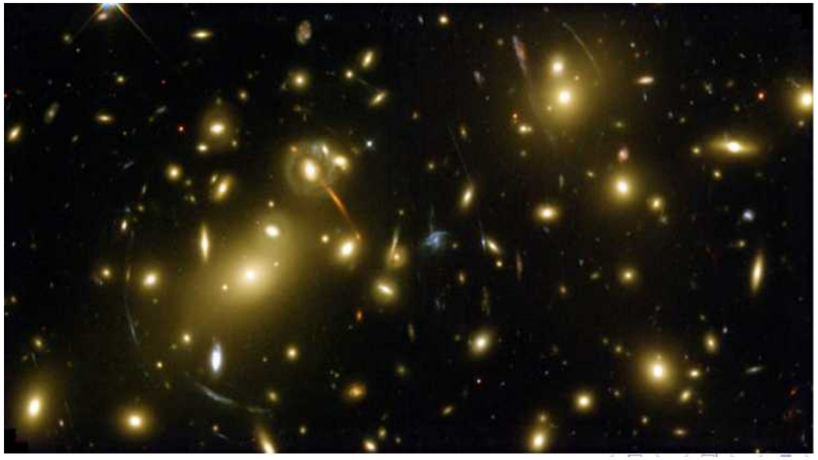
Variation of cluster properties with:

- Dynamical state (mergers)
- Morphology (ellipticity)

Part II :
LSS OBSERVATIONS

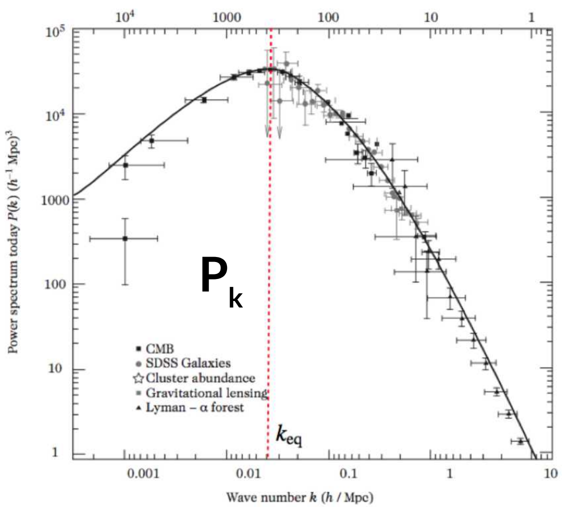


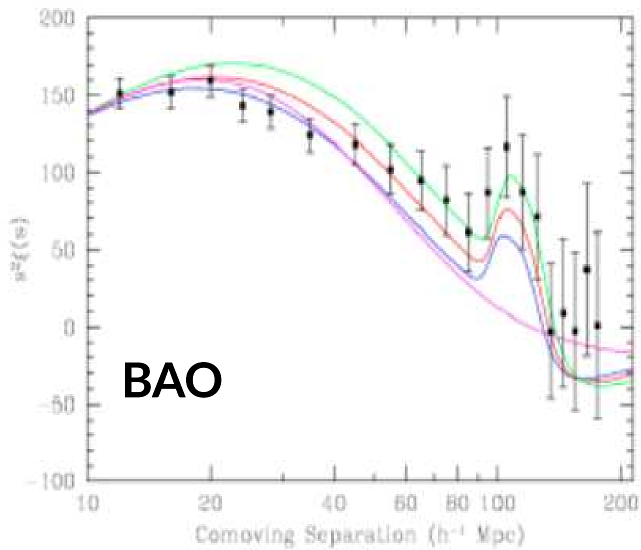




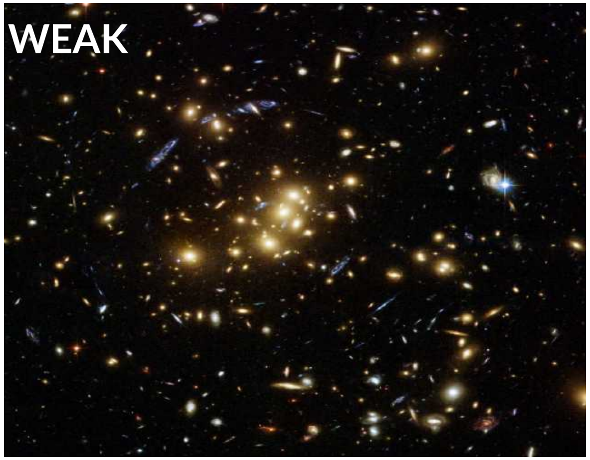
LSS observables

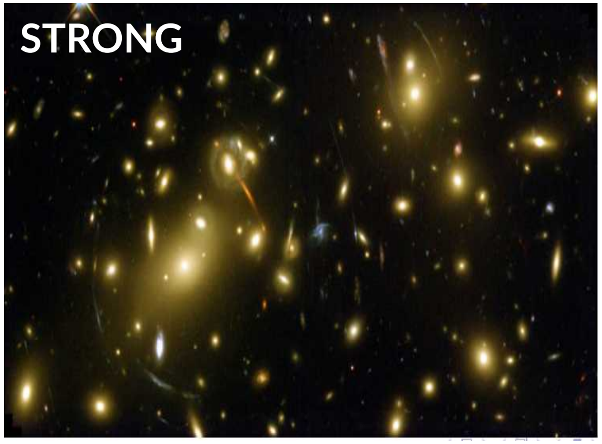
- **Galaxy clustering**



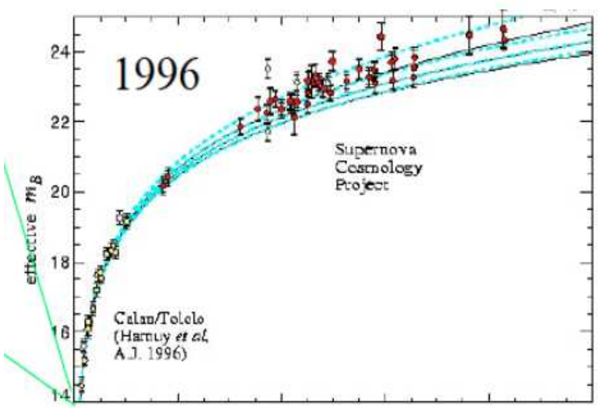


- **Lensing : weak & strong**

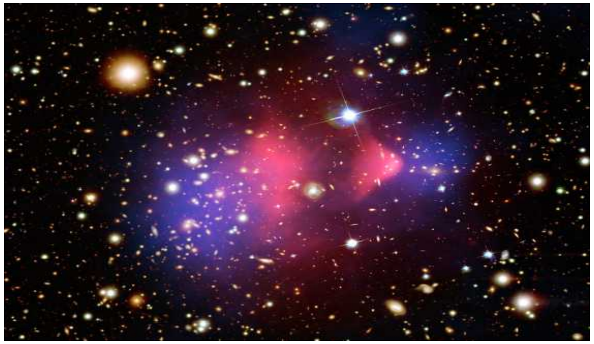




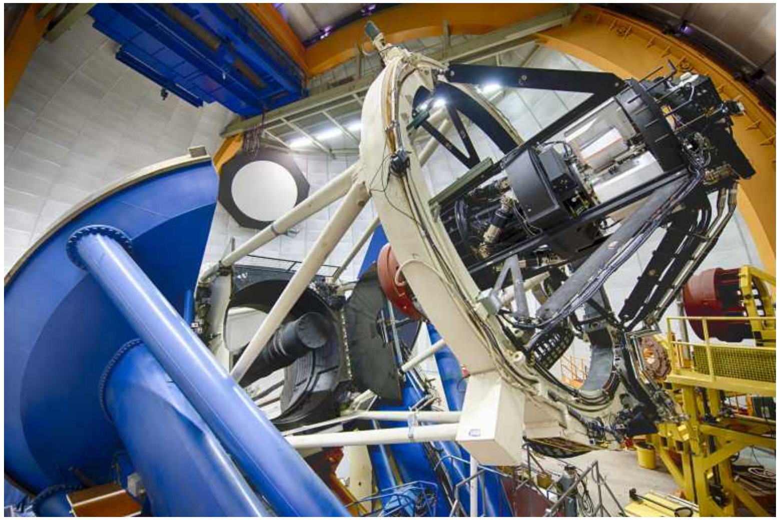
- **Supernovae type I**



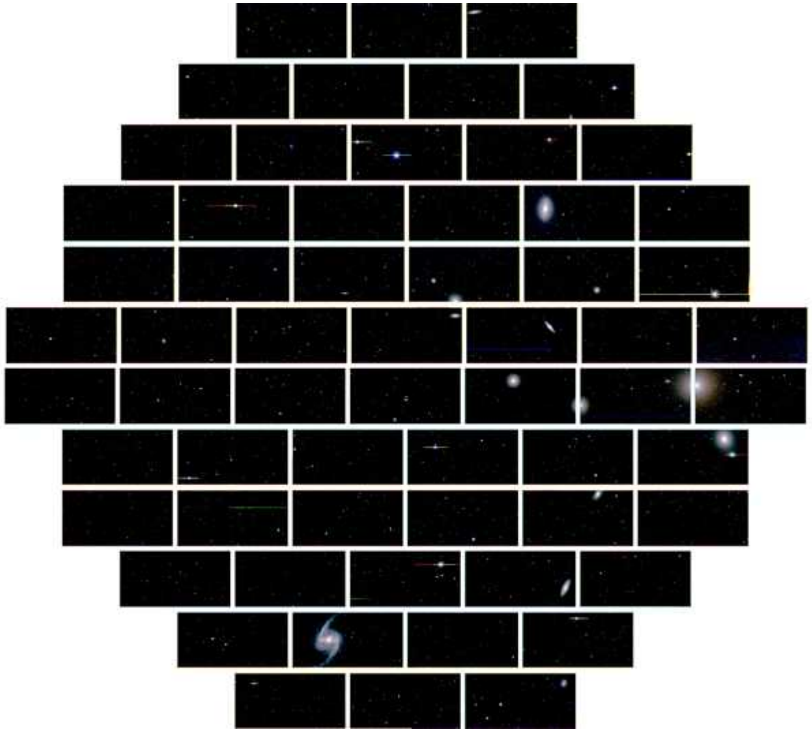
- **Clusters of galaxies**



DES (Dark Energy Survey)



DECam : DES 570 Megapixels camera mounted at the V.Blanco 4 m telescope at Cerro Tololo (Chile)



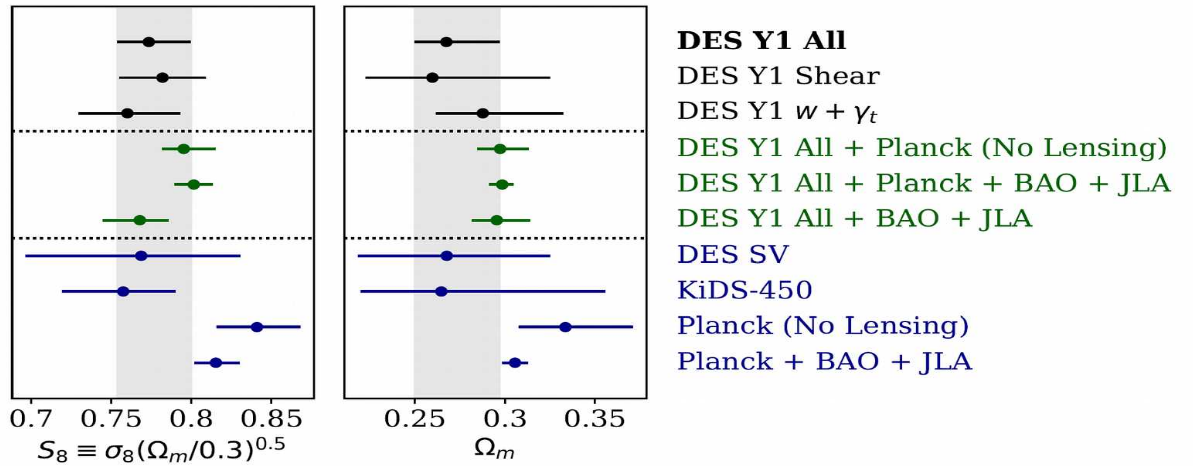
Six years of observations from 2013-2019 (758 nights)

Survey of 5000 square degrees in five filters with a 570 Megapixels camera

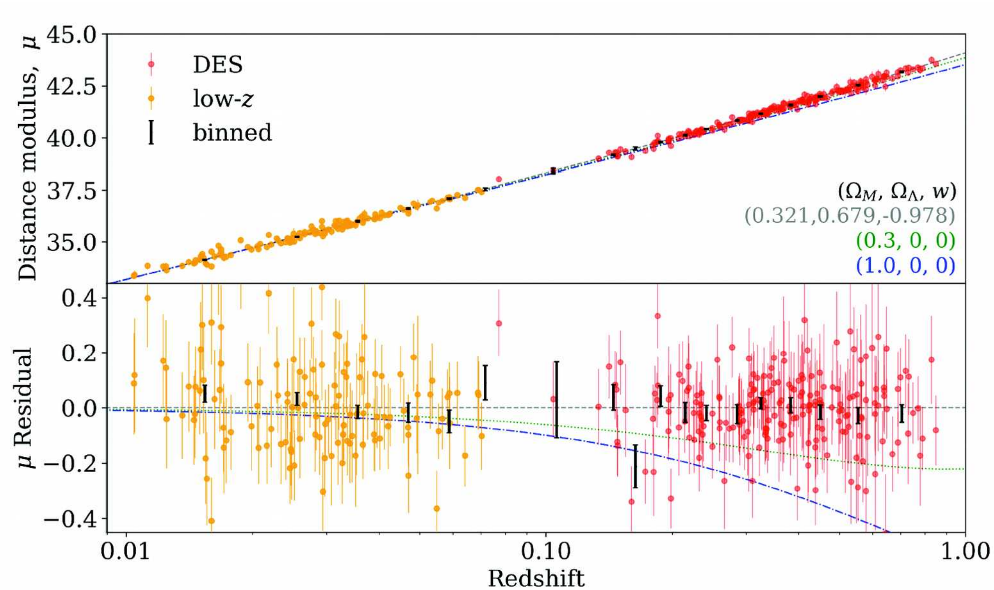
300 million of galaxies observed

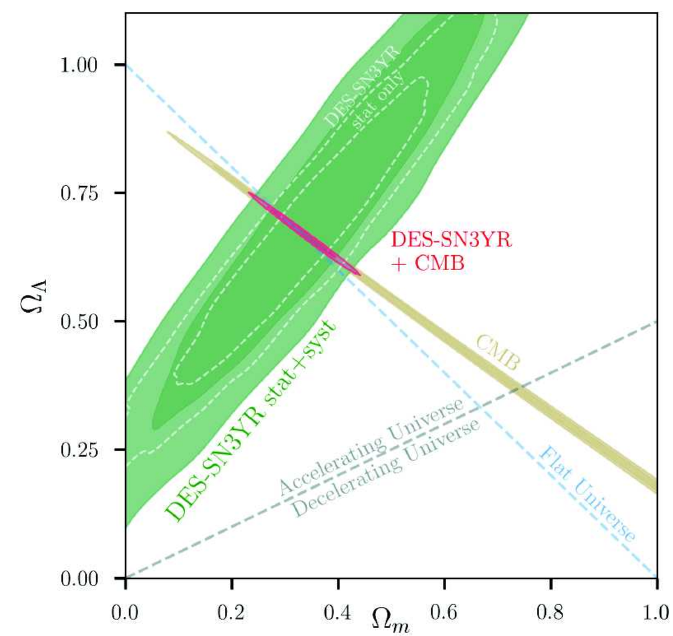
Selected DES main results

Constraints from galaxy clustering and weak lensing



Supernova Hubble diagram





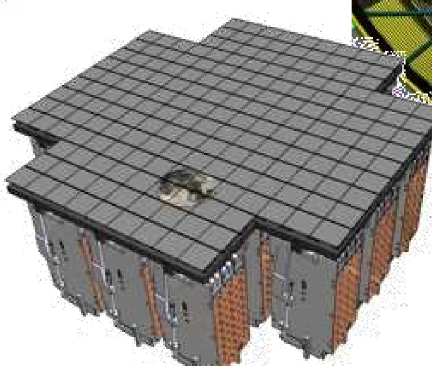

Cerro Pachón – Future site of the LSST
LSST Rendering
on El Peñón
SOAR
Gemini
Cerro Pachón
ridge – view from
northwest

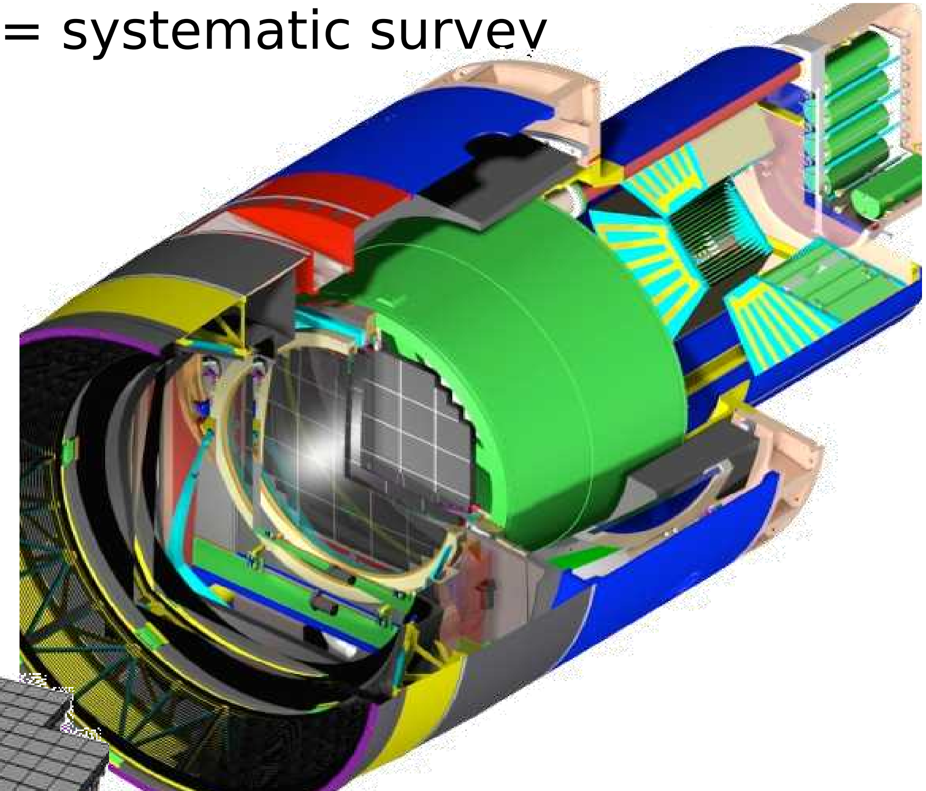

LSST
Large Synoptic Survey Telescope
First lights 2021
Survey from 2023 to 2033

LSST must scan ~1/2 of the visible sky every 3/4 nights during 10 years in 6 frequency bands with high sensitivity

Large = big
Synoptic = view all
Survey = systematic survey

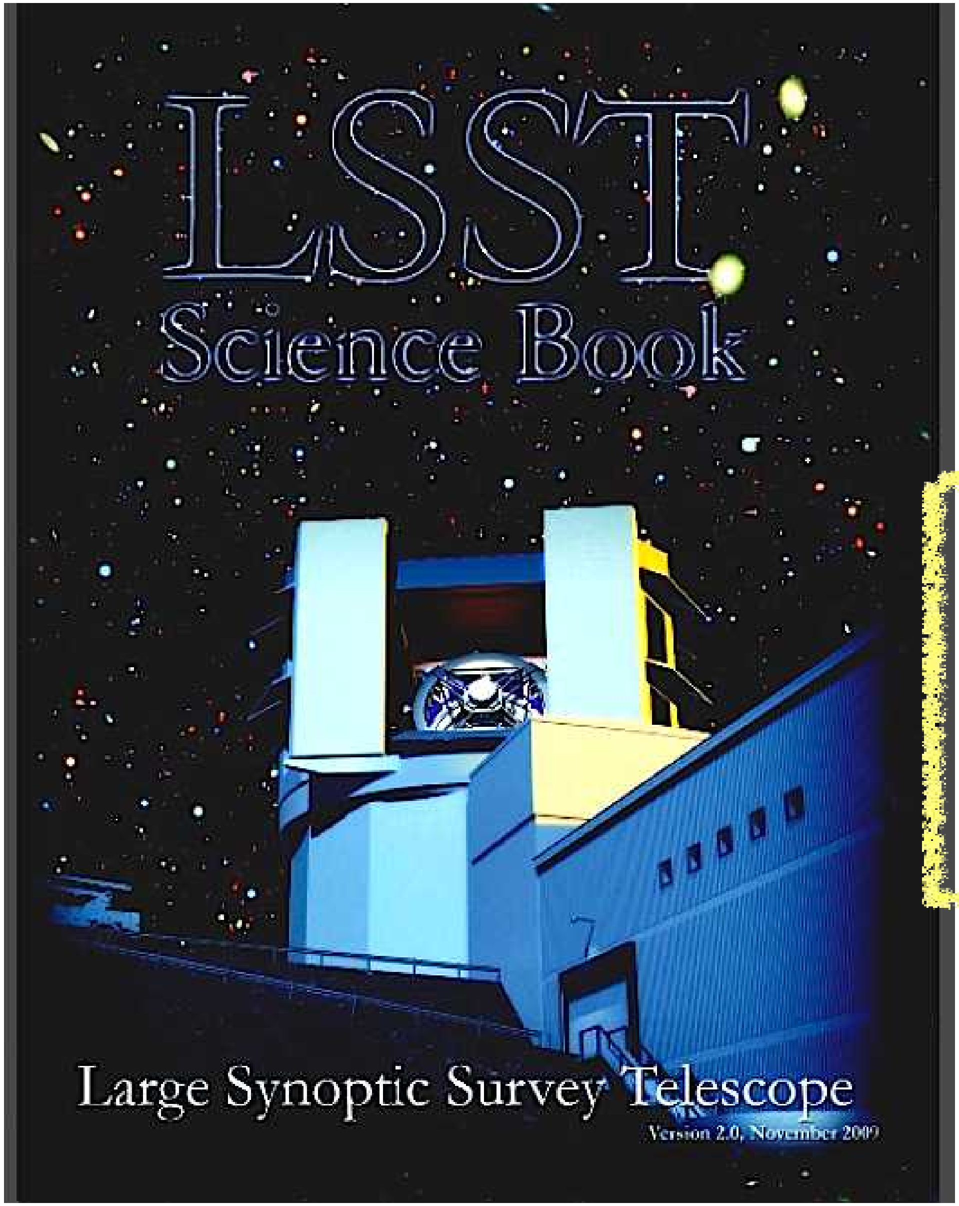
8.4 m diameter telescope to be able to detect faint objects





Large FOV camera with 6 filters from nearby IR to nearby UV,
3 millards of pixels

LSST scientific program



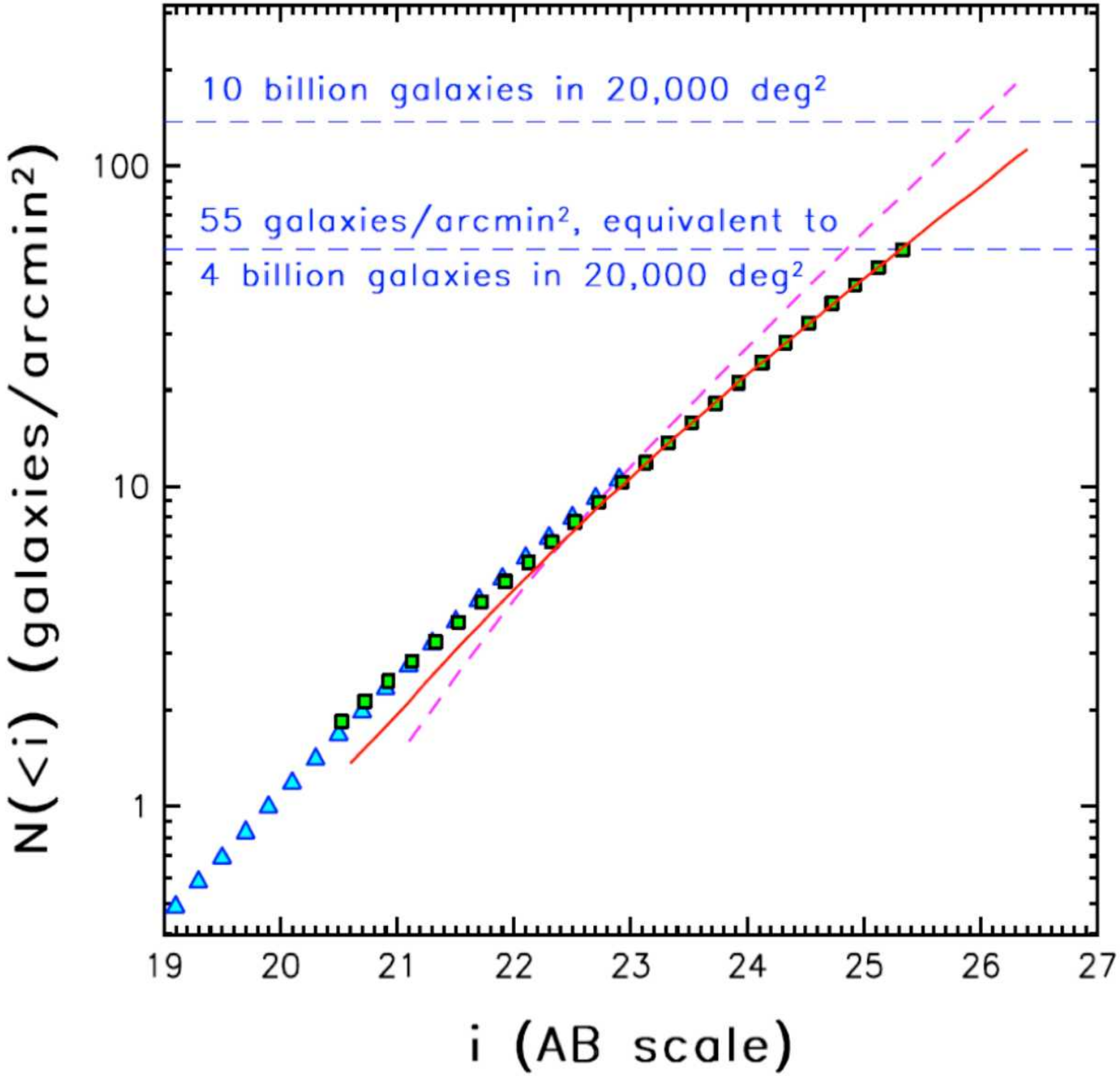
- ➔Solar system objects
- ➔Stellar populations
- ➔Our galaxy and the local environment
- ➔Variable sky objects
- ➔galaxies
- ➔Actifs galaxies
- ➔supernovae
- ➔Strong lensing
- ➔Weak lensing
- ➔Galaxy clustering
- ➔Clusters of galaxies

cosmologie

IN2P3 labs are fully involved in cosmological studies

www.lsst.org/lsst/scibook

Mesure the position/redshift of milliards of galaxies



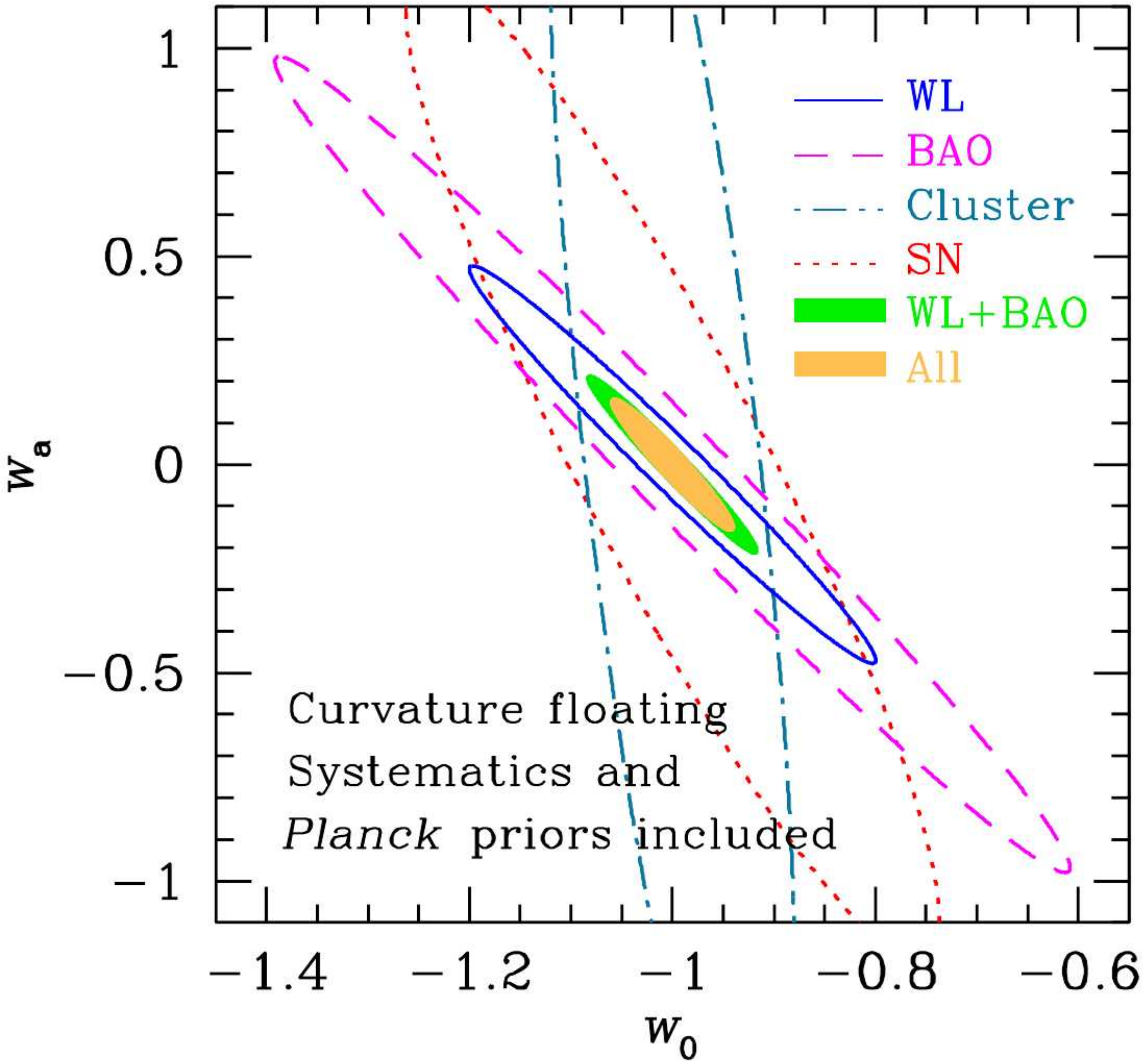
To use galaxies for cosmology we need to measure their redshift

Accurate photometry in 6 bands = very low resolution spectroscopy

Need to estimate redshift for 3-4 milliards for galaxies up to z=2-3

Although photometric redshift uncertainties smear out the distribution, the large statistic allows us to use galaxies for cosmology

Precision/accurate cosmology
Multi-Probe analysis



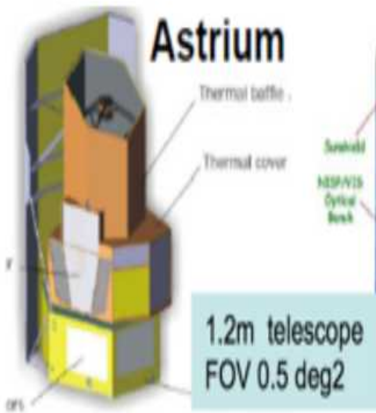
Example :

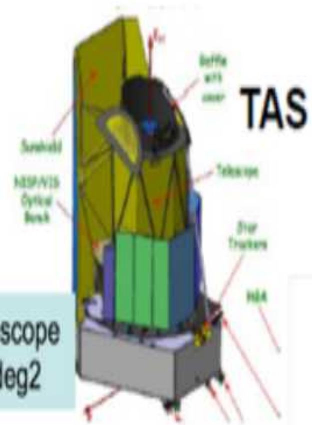
Measuring the nature of dark energy

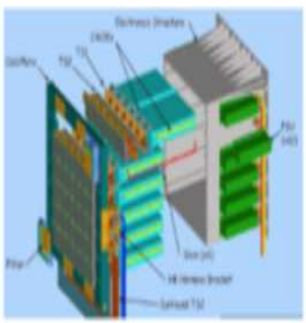
$$p = w\,\rho$$
$$w(a) = w_0 + w_a\,(1-a)$$

EUCLID

The EUCLID instrument







The Visible imager (VIS)
36 E2V CCD, 0,1"PSF
1 broad band R+I+Z (550-900nm)

The Infrared spectro/photometer (NISP)
16 H2Rg infra red pixel detectors,0,3" PSF,
3 IR bands Y,J,H (920-2000 nm)
NIR slitless spectroscopy (1100 – 2000 nm) R ~ 350

- M class ESA space mission
- All-sky visible and IR observations in photometry and spectroscopy
- Exposure depth 24 magnitudes
- 2 surveys : shallow (15000 deg^2), deep (2 x 20 deg^2)
- Consists of 2 channels, and 3 instruments :
  - VIS, optical imager for lensing reconstruction (550-900 nm)
  - NISP, IR photometer (900 – 2000 nm) and spectrometer (1100- 2000 nm)
- Launch 2020-2021
- 7 years operation
- International collaboration, IN2P3 fully involved

EUCLID cosmological probes

Weak lensing (WL)

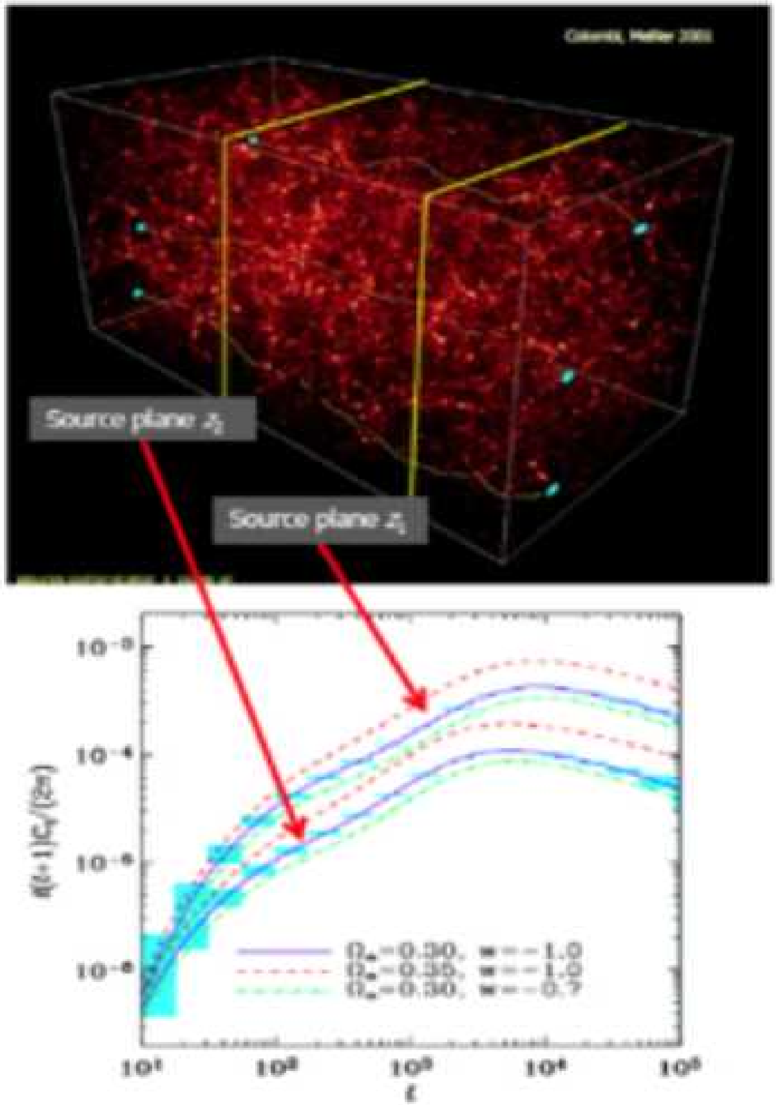
• distribution of matter, expansion history, growth rate, tomography
• 3-D cosmic shear measurements 0 < z< 2
• shape and photo-z from optical and NIR data
• 1.5 billion galaxies

Galaxy clustering (GC)

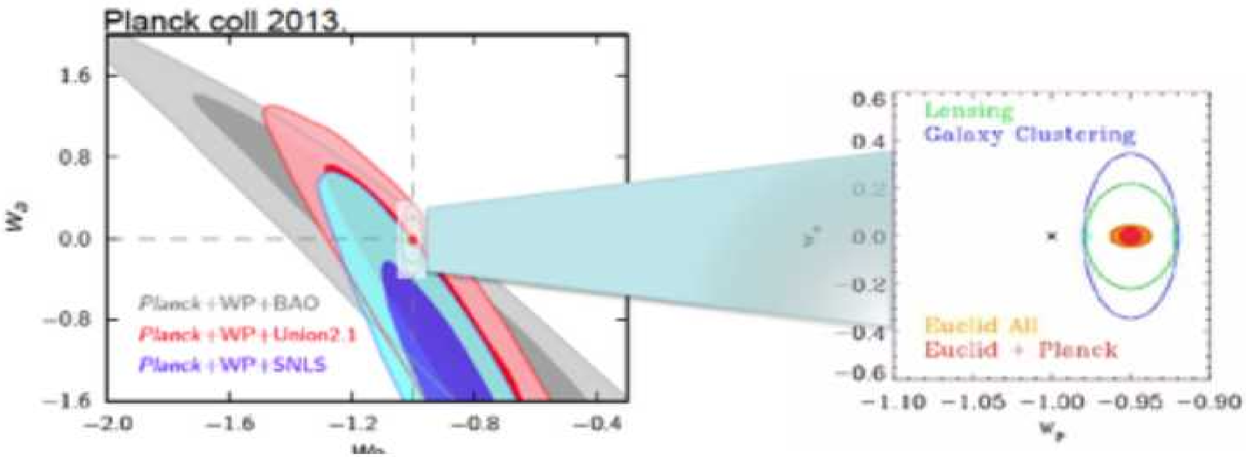
• distribution of matter, expansion history, growth rate, tomography
• 3-D position measurements 0.7 < z< 2
• 3D distribution of galaxies from spectroscopy redshift
• measure position of 50 millions galaxies

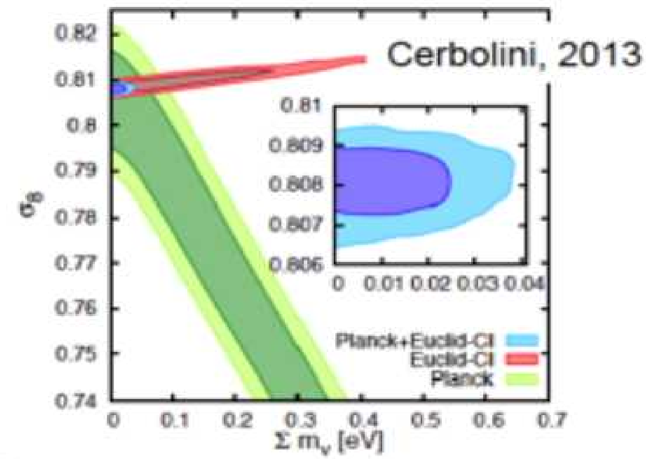
Clusters of galaxies

• measure cluster number counts as a function mass and redshift, power spectrum statistics,
• detection of about **60000** clusters



EUCLID expected performance





	Dark energy			neutrinos	Initial conditions	Modified gravity
Parameter	**w_p**	**w_a**	**FOM**	**mν (eV)**	**F_{NL}**	**γ**
Euclid alone	**0,013**	**0,048**	**1540**	**0,027**	**5,5**	**0,009**
Euclid +Planck	**0.007**	**0.035**	**4020**	**0.019**	**2.0**	**0.007**
Current	**0.1**	**1.5**	**~10**	**0.58**	**100**	**0.2**
Improve factor	**>10**	**>50**	**>400**	**30**	**50**	**30**

The Euclid mission