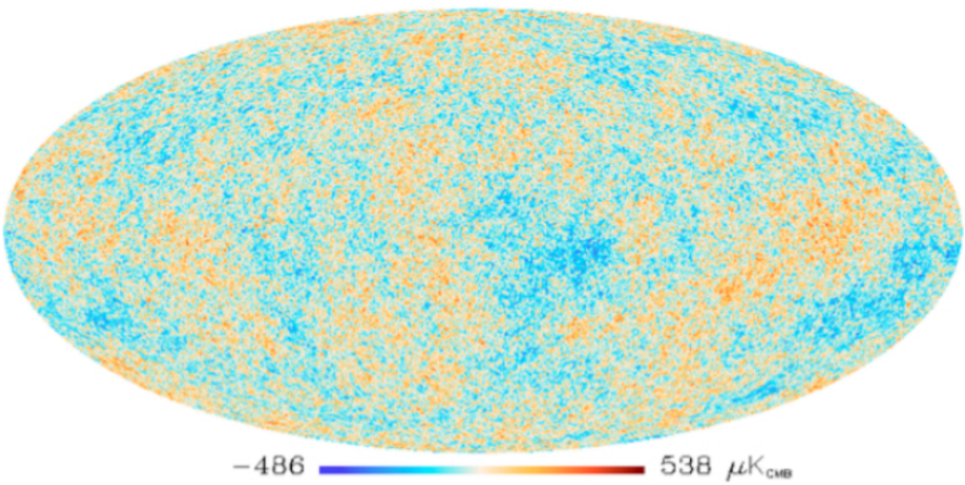
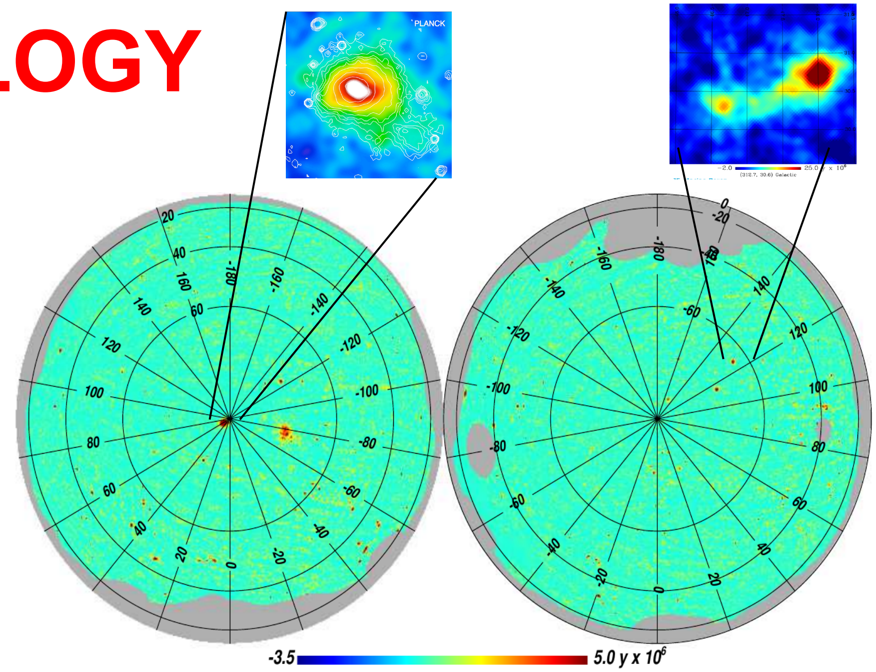
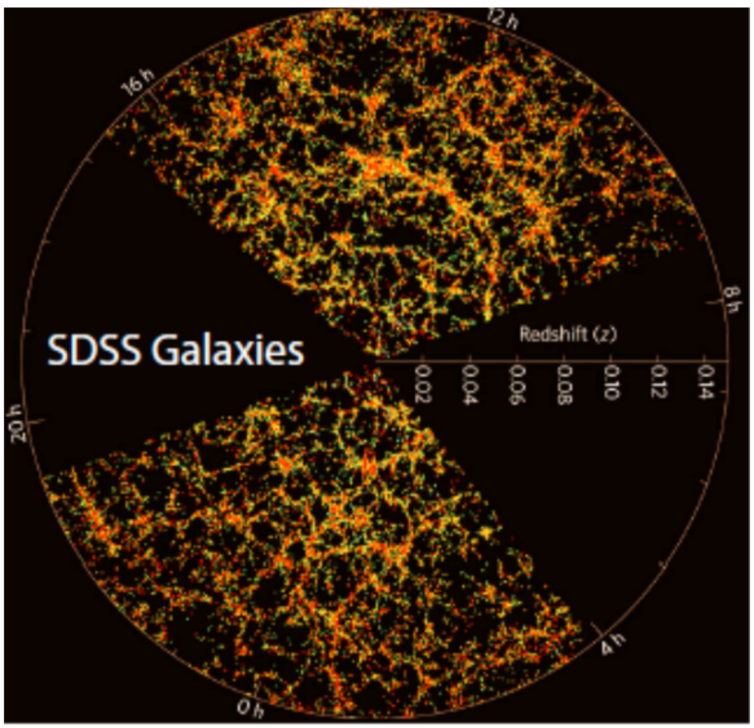
OBSERVATIONAL COSMOLOGY

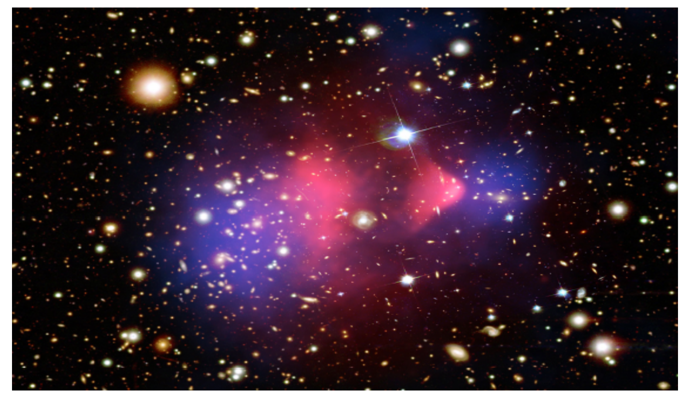
J.F. Macías Pérez







EXPERIMENTS



Observational facts in cosmology

- **Galaxy distribution**

- the universe is expanding
- small structures form first and combine to form larger ones

- **Supernovae type Ia**

- currently expansion is accelerated: dark energy

- **Cosmic Microwave Background (CMB)**

- the universe is isotropic and homogeneous
- universe fully thermalized
- density fluctuations of the order of 10^{-5}

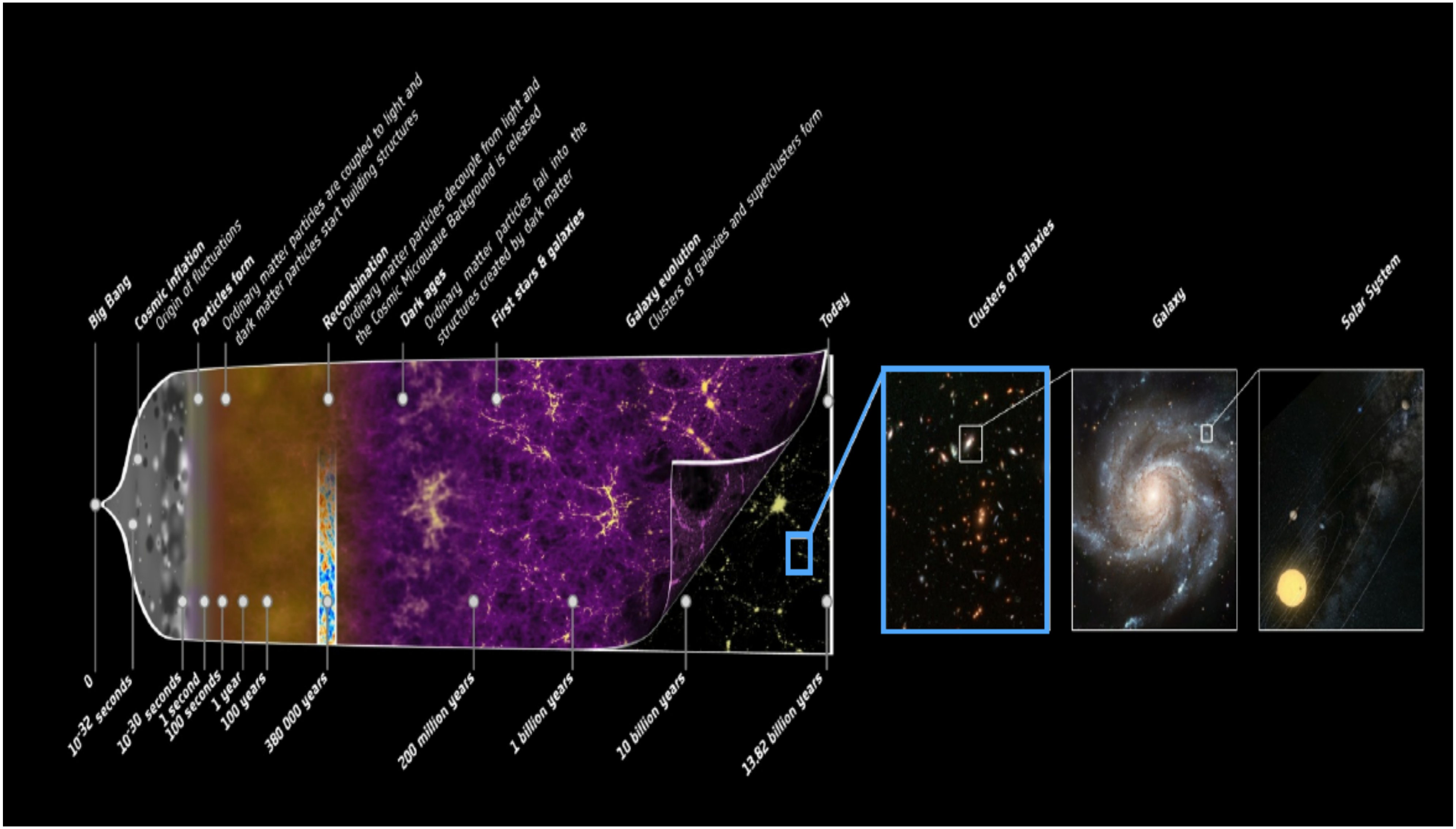
- **Abundance of light elements**

- Light elements form first from nucleosynthesis

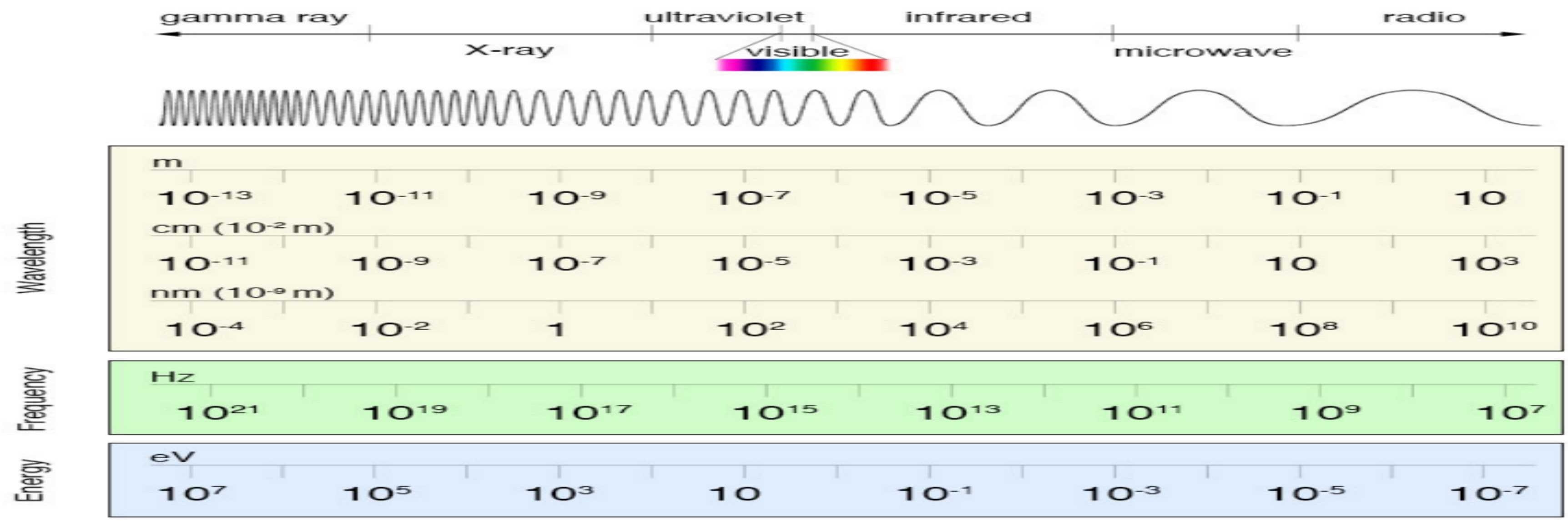
- **Dynamics of galaxies and of cluster of galaxies**

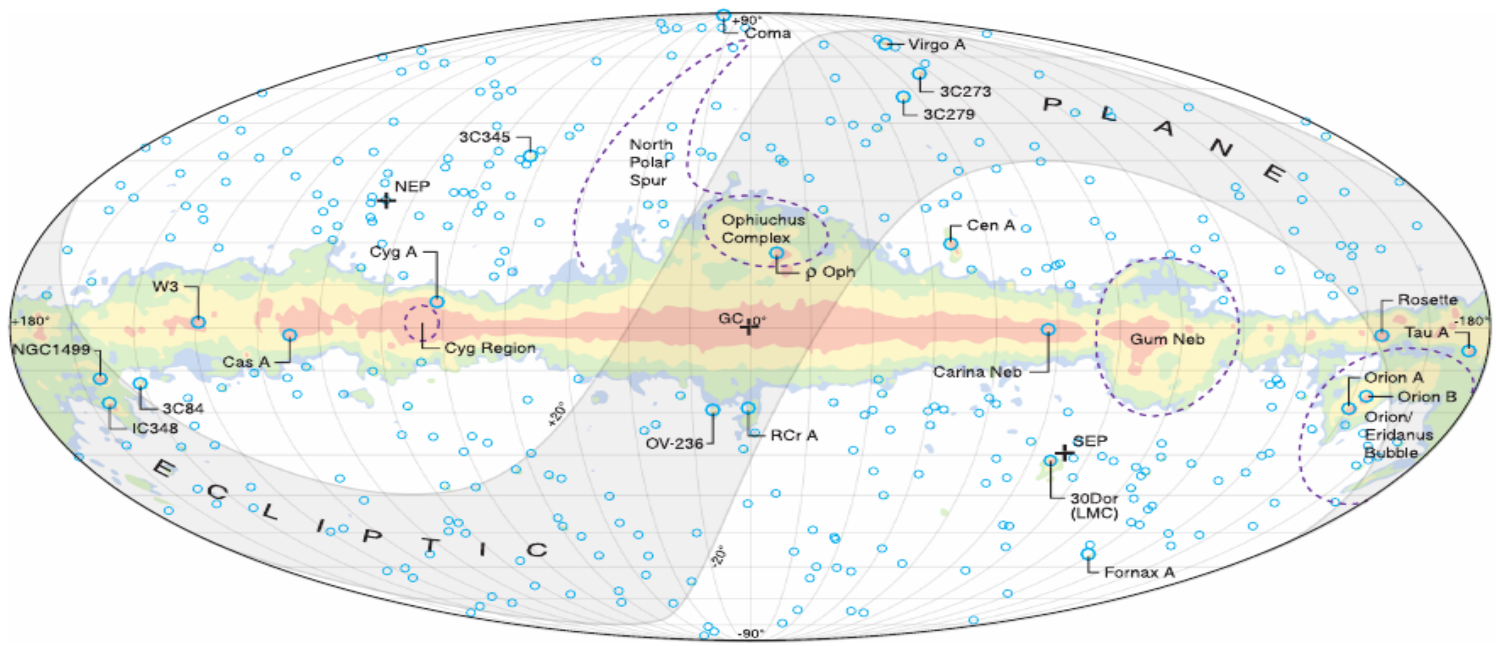
- Evidence for extra matter component: dark matter and/or modified gravity theory

Brief history of the univers

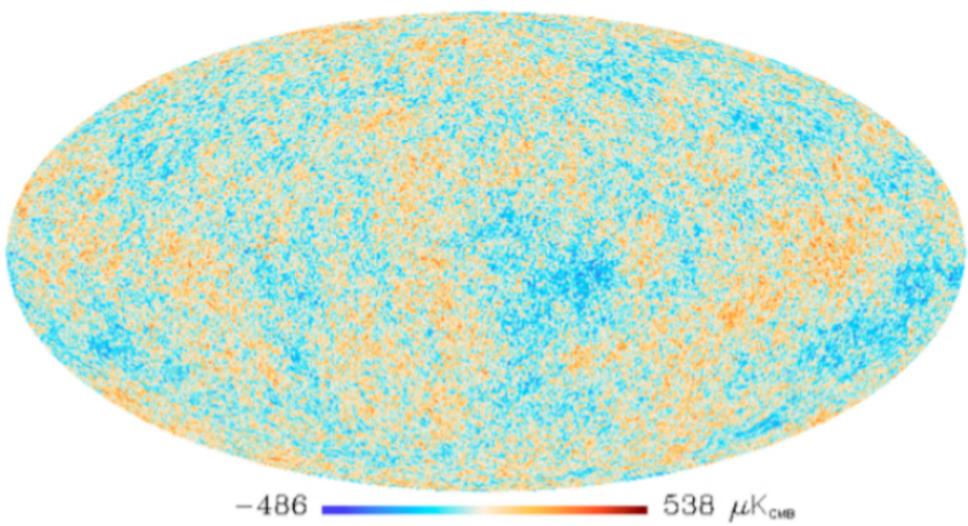


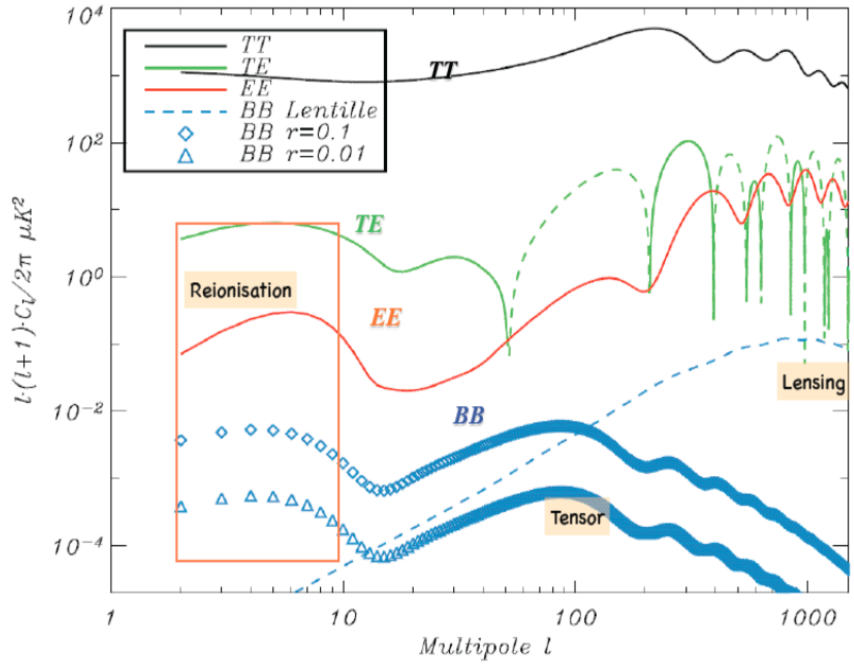
Observing the sky

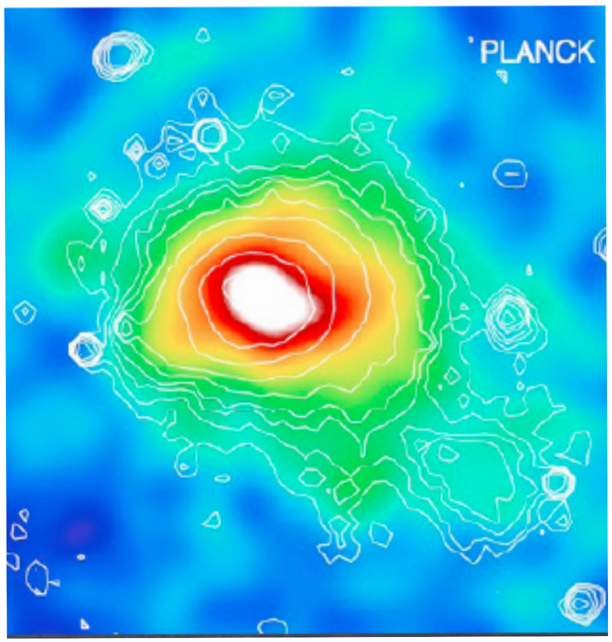




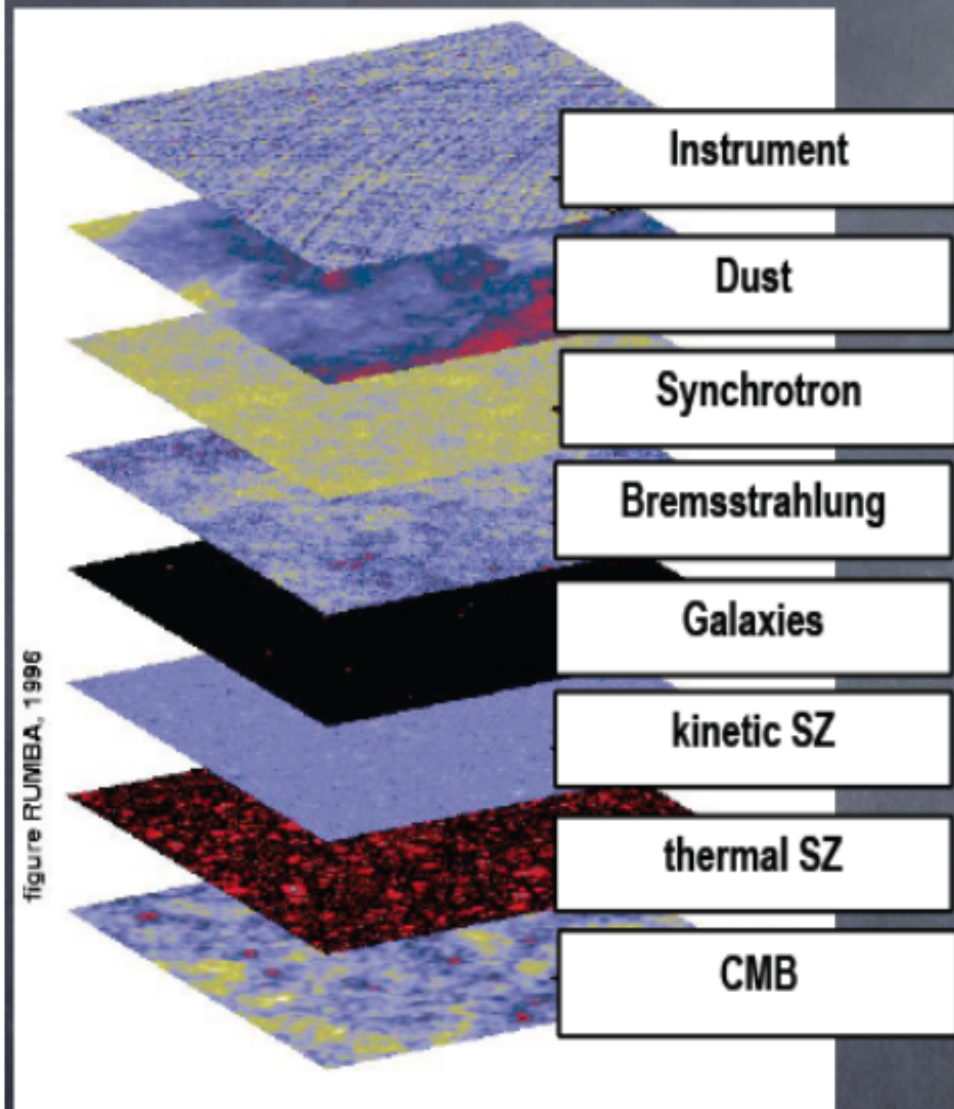
Part I :
CMB OBSERVATIONS

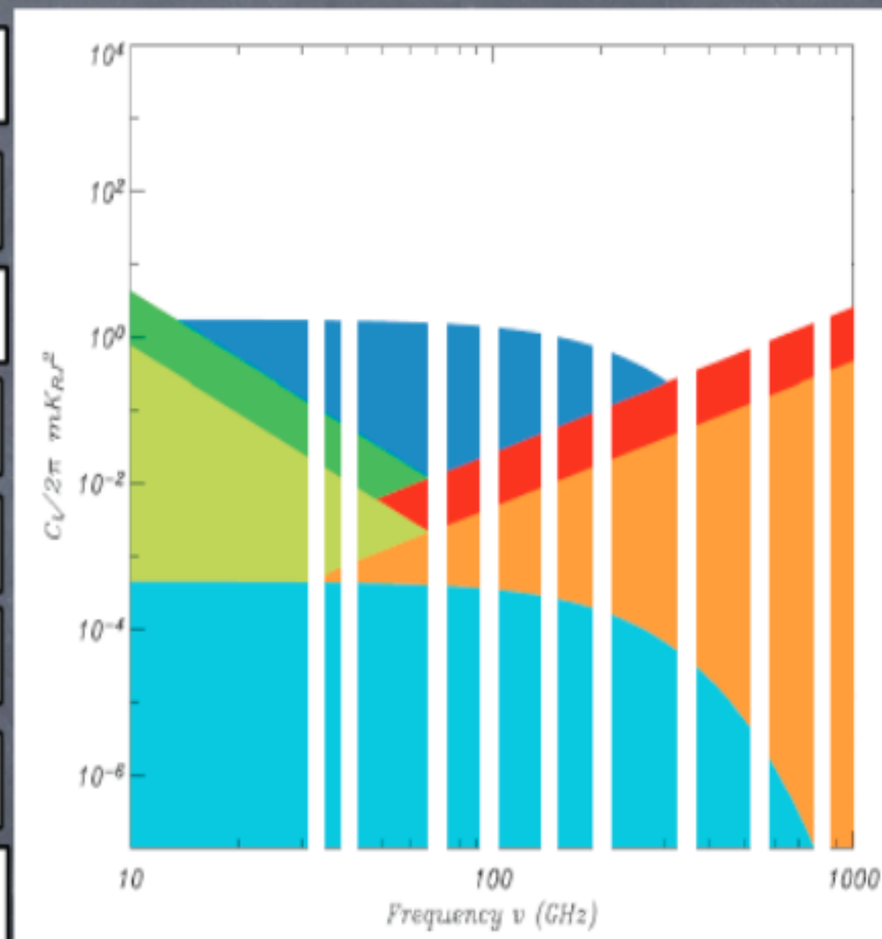




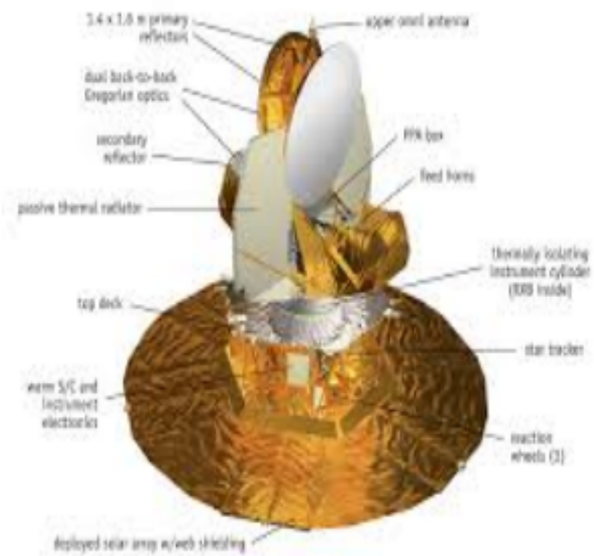


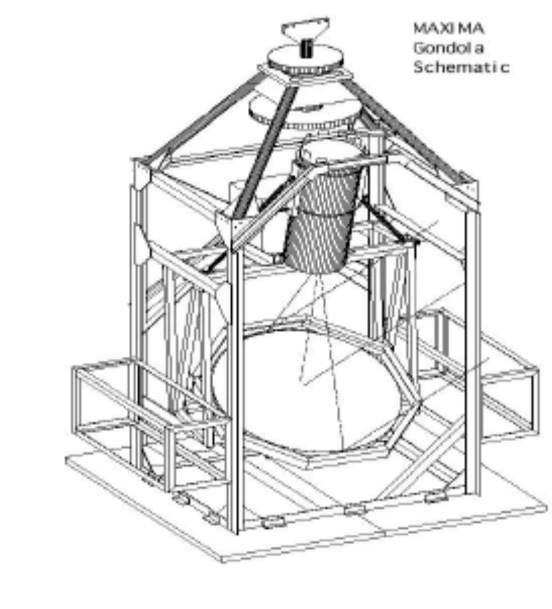
Observing the « CMB » sky





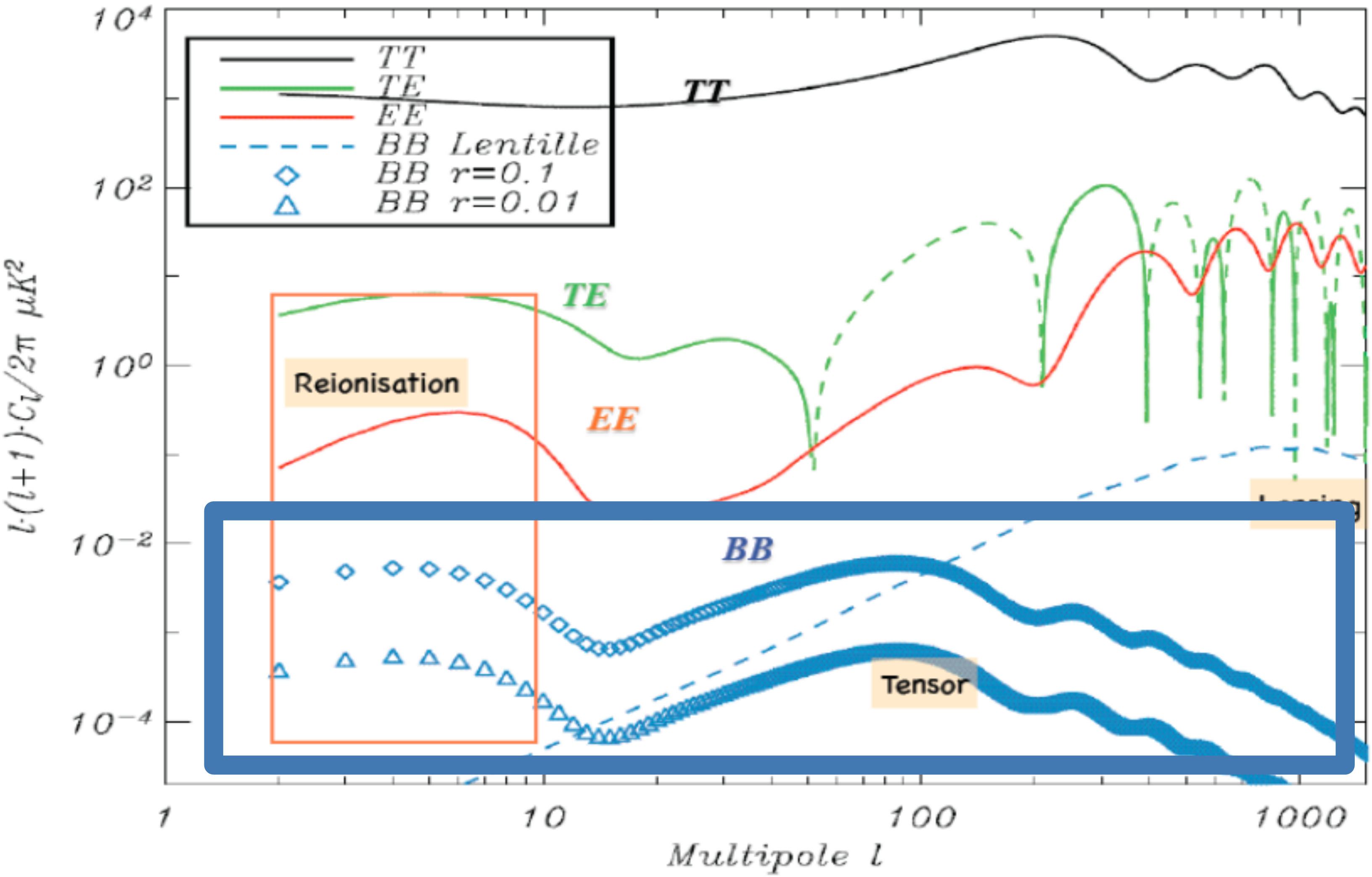
CMB experiments





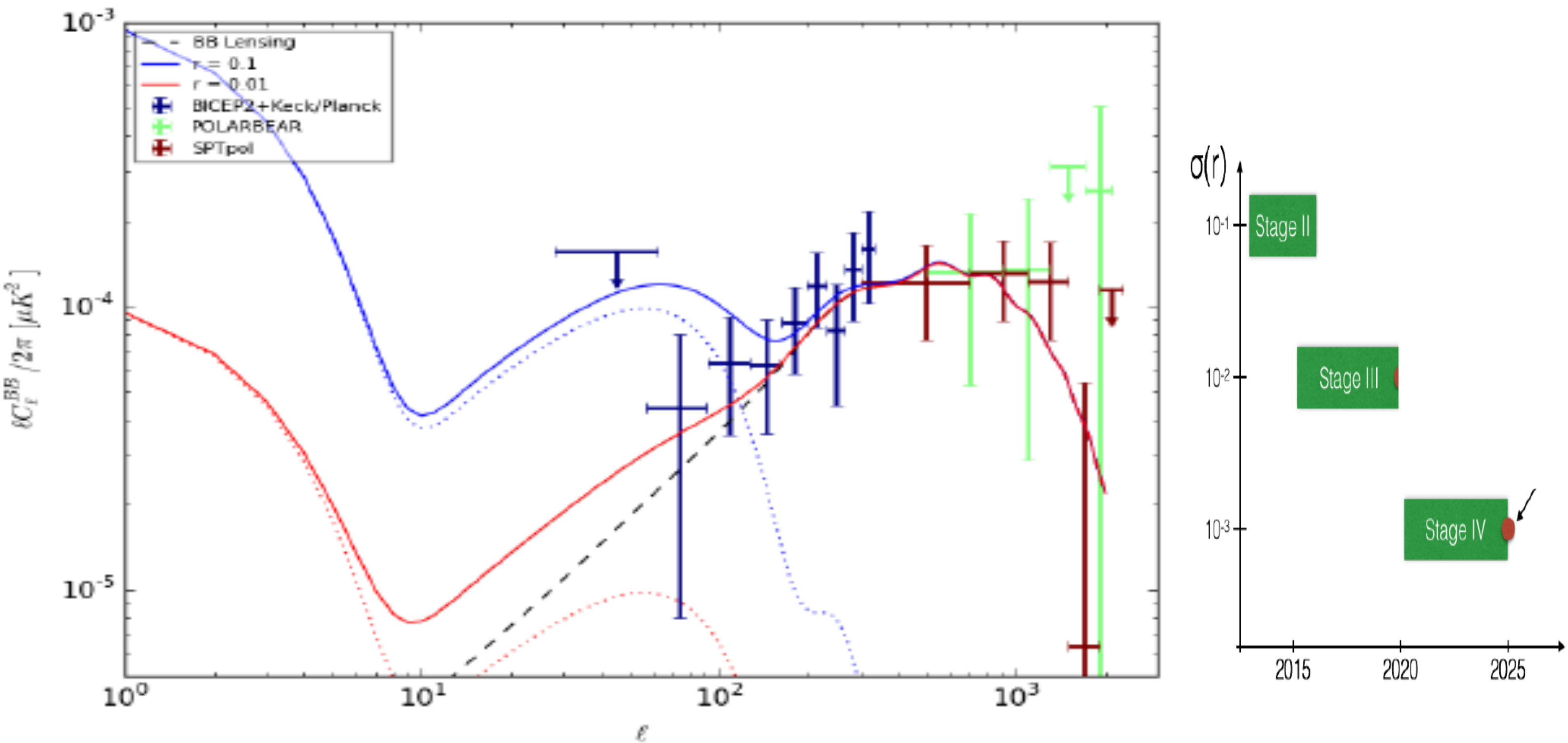
	Radio	mm
Telescopes	dish and horns	dish and horns
Detectors	HEMT + square law detectors	bolometer and/or KIDs
Cooling	18-50 K	100-300 mK
Observing mode	Ground, satellite	ground, balloon, satellite

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



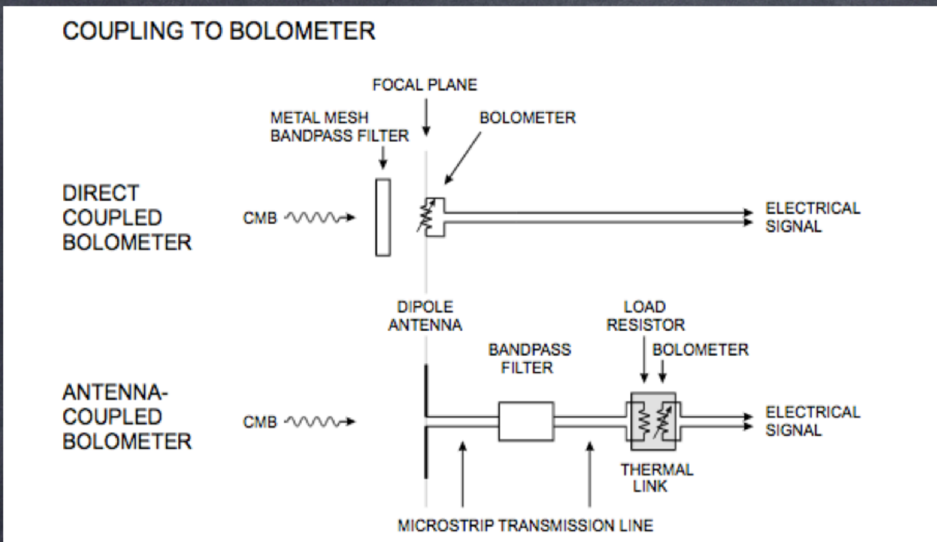
CMB B-modes measures the tensor-to-scalar ratio, r, which is directly related to inflation energy scale

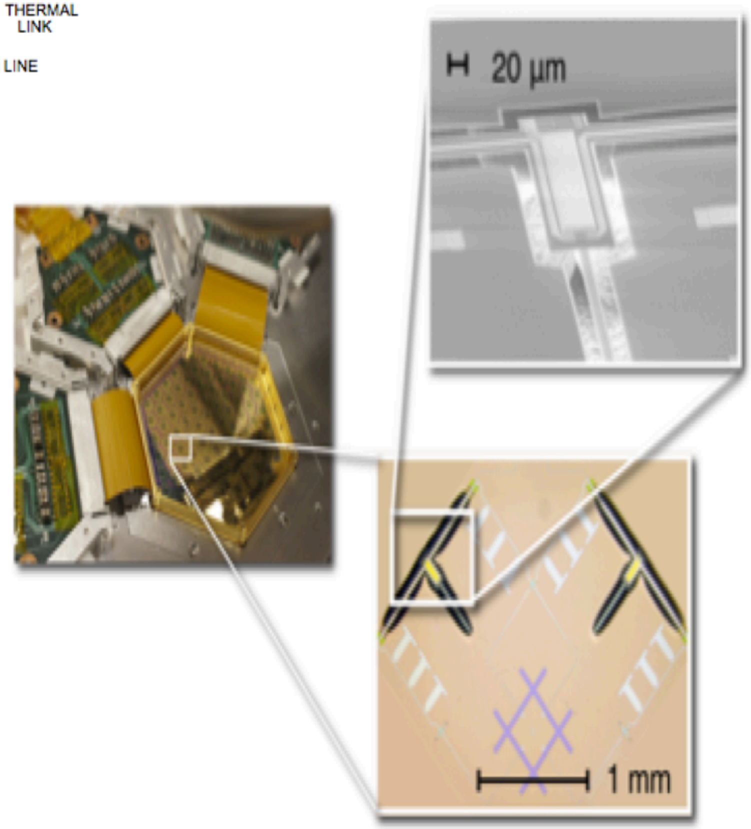
CMB intensity and polarisation power spectra : the quest for B-modes

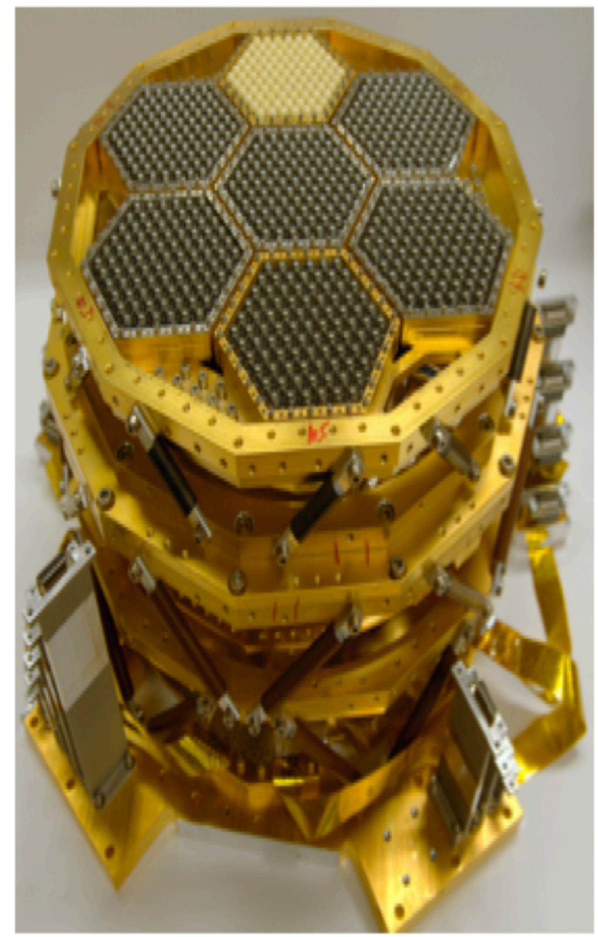


Current results are limited by foreground contamination, r<0.07 @ 95 % C.L. [BICEP, KECK & Planck]

Antenna coupled TES detectors



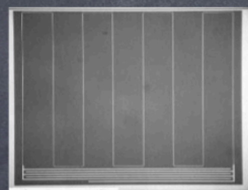
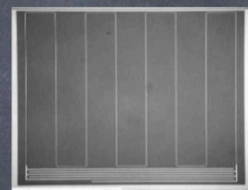
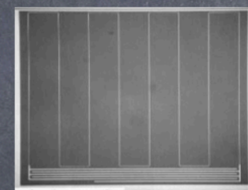


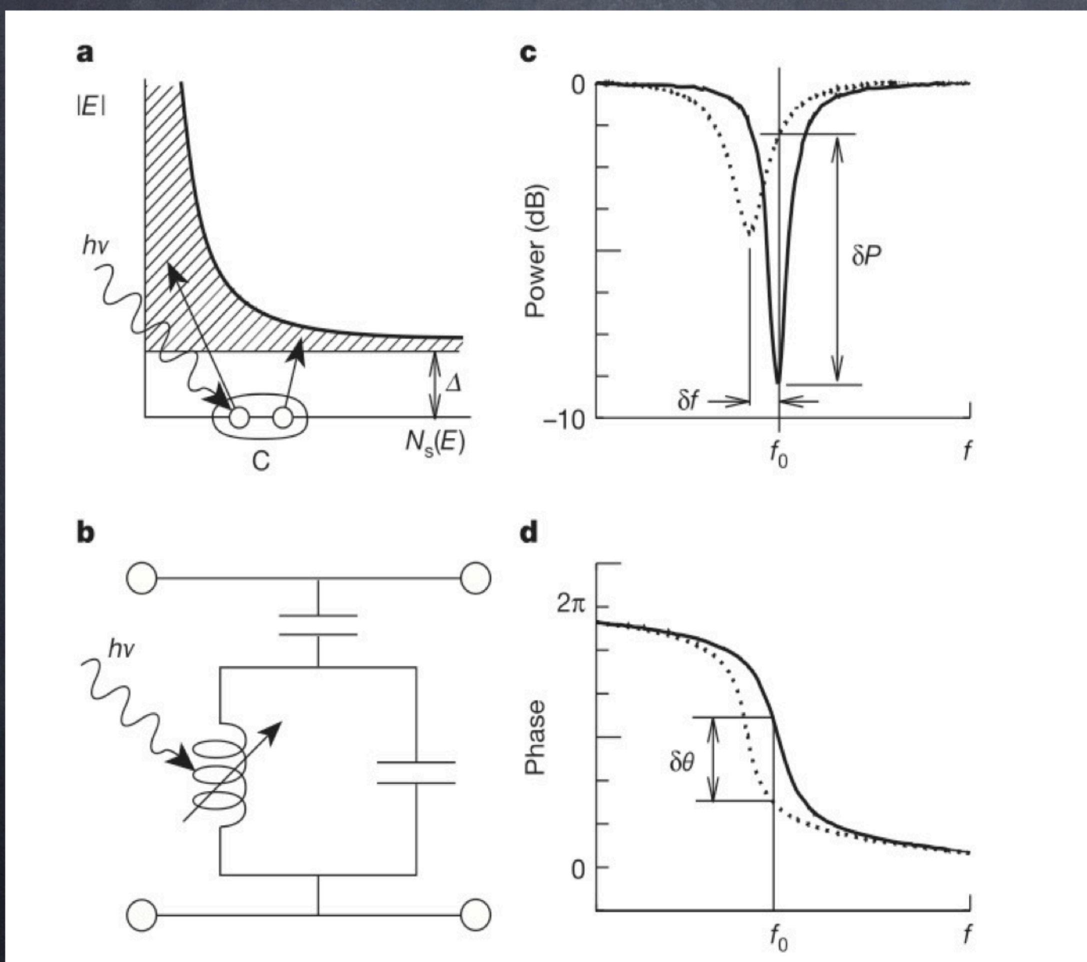


KIDs in a nutshell

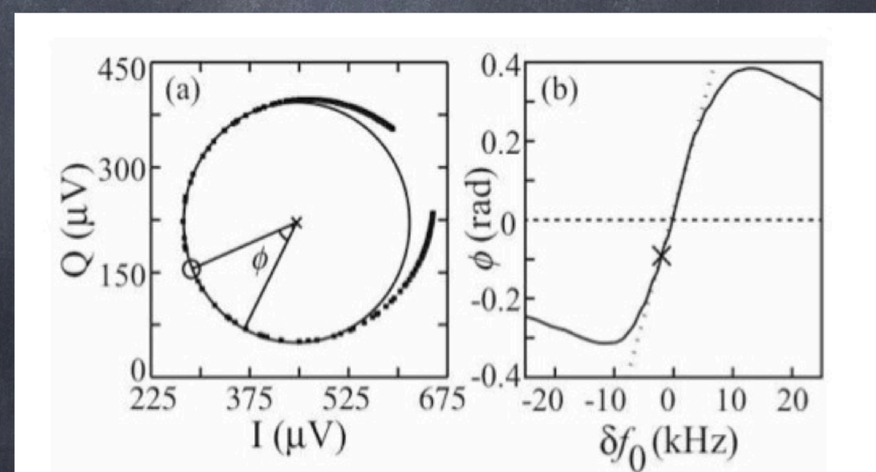
Superconducting Microwave Resonators coupled to a feed line

IN OUT



Resonance frequency changes with received power



« 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

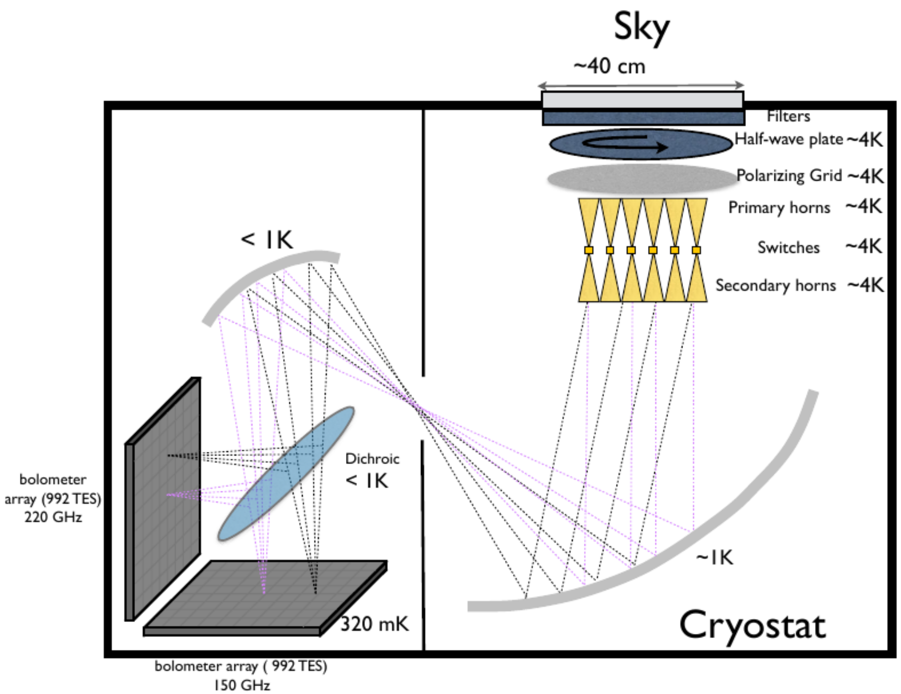
+ proposed satellites : LITEBIRD (2027), CORE (2035?),

.....

+ ground S4 (2030 ?)

Q&U Bolometric Interferometer for Cosmology

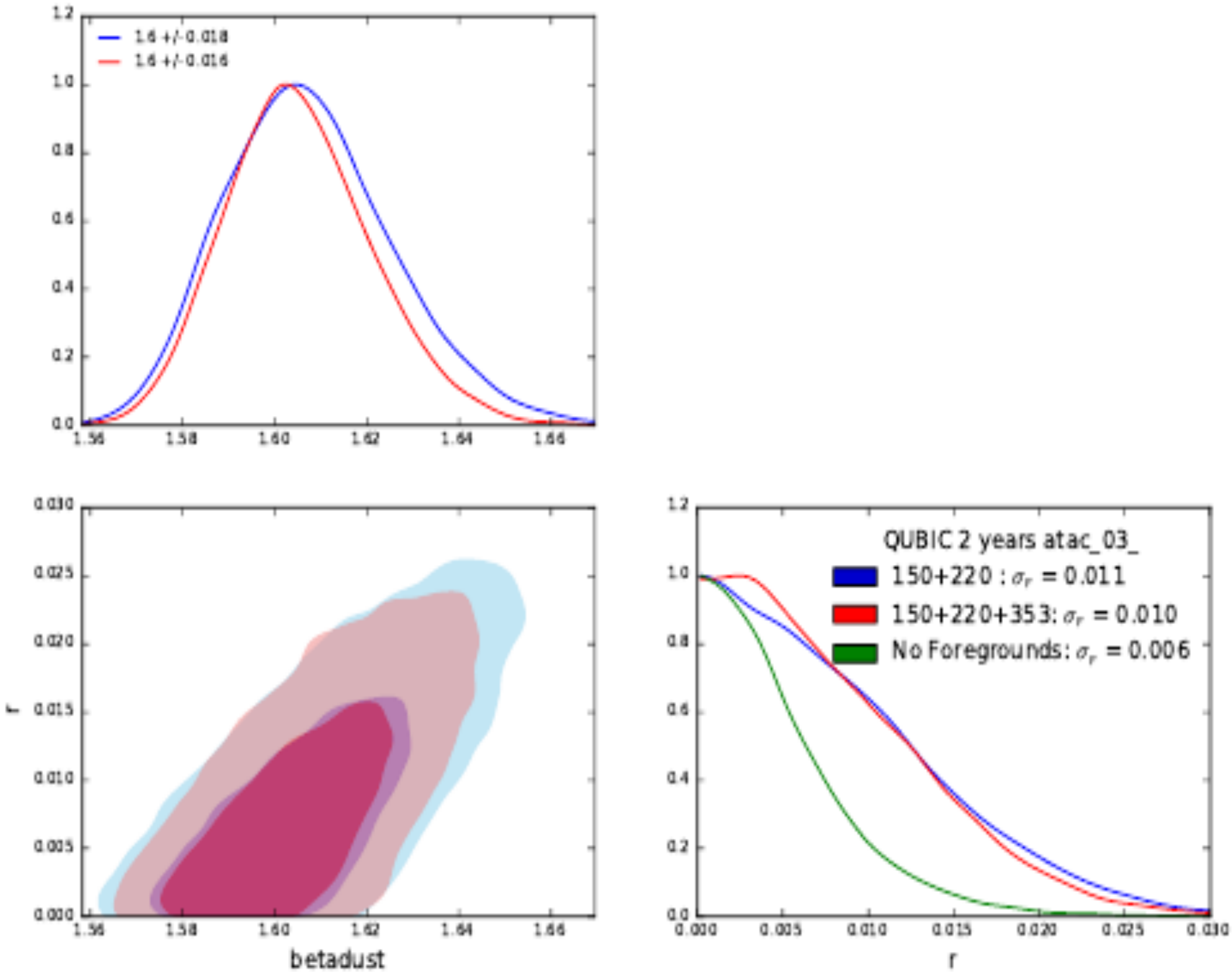
QUBIC design and expected performance

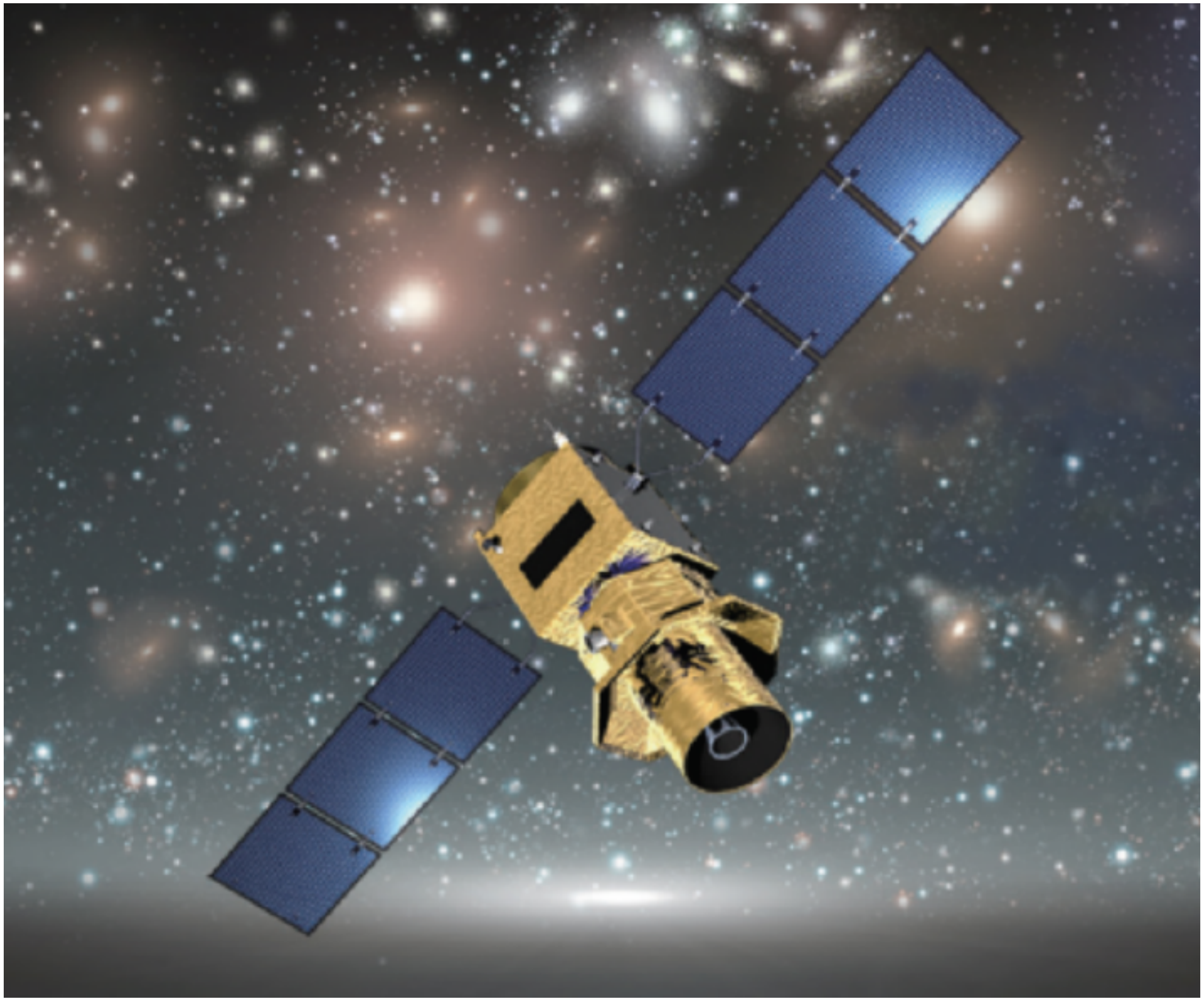


- Dual band TES bolometer interferometer
- Cold continuosly rotating Half-wave-plate
- Designed for deeo control of systematics
- To be installed in Alto Chorrillos, Argentina
- First module tests expected in 2018
- Operations 2019-2021
- International collaboration : APC, LAL, ...

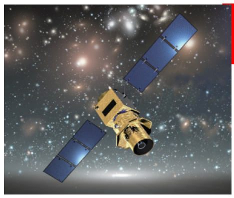
Frequency channels	150 and 220 GHz
Bandwidth	25%
Number of horns (interferometric elements)	400
Primary beam FWHM at 150 GHz	12.9 degrees
Primary beam FWHM at 220 GHz	15 degrees (not gaussian)
Number of detectors	2x1024

QUBIC design and expected performance

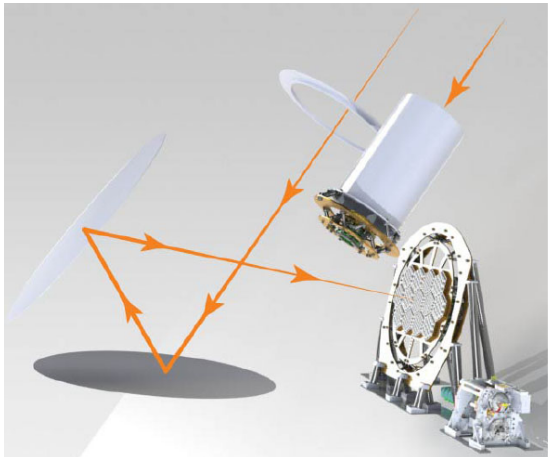


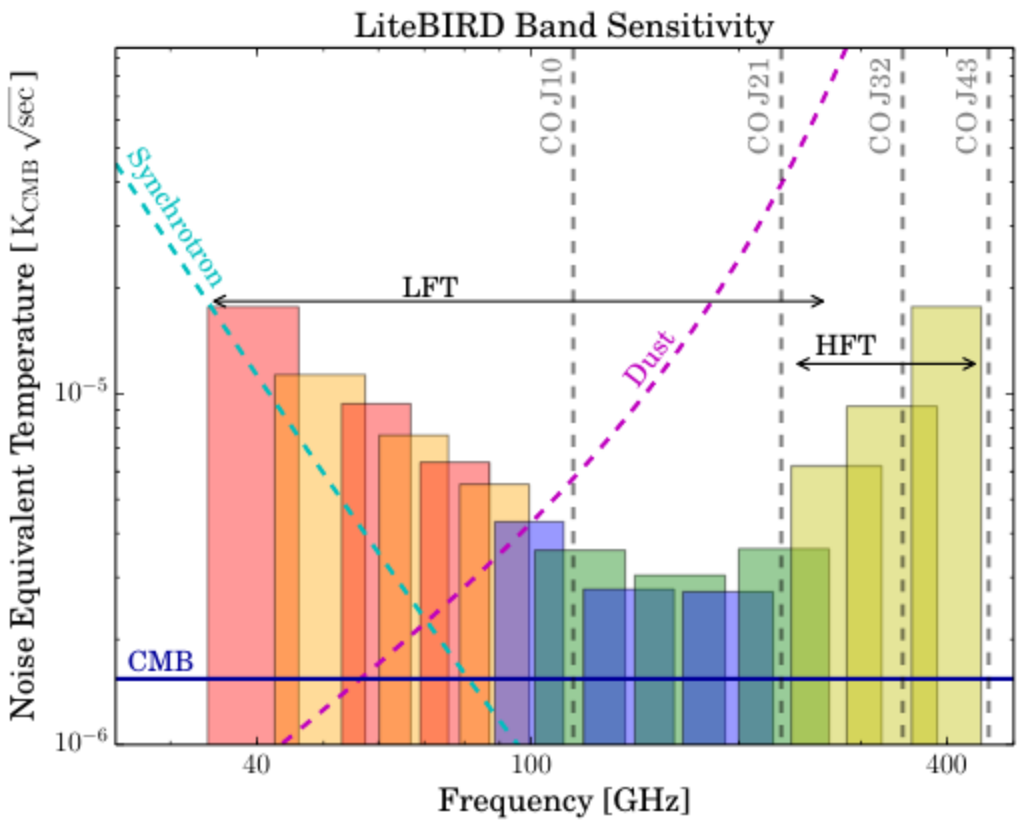


LITEBIRD satellite

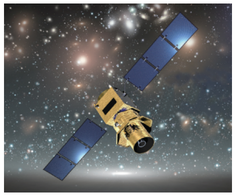


LITEBIRD design and expected performance

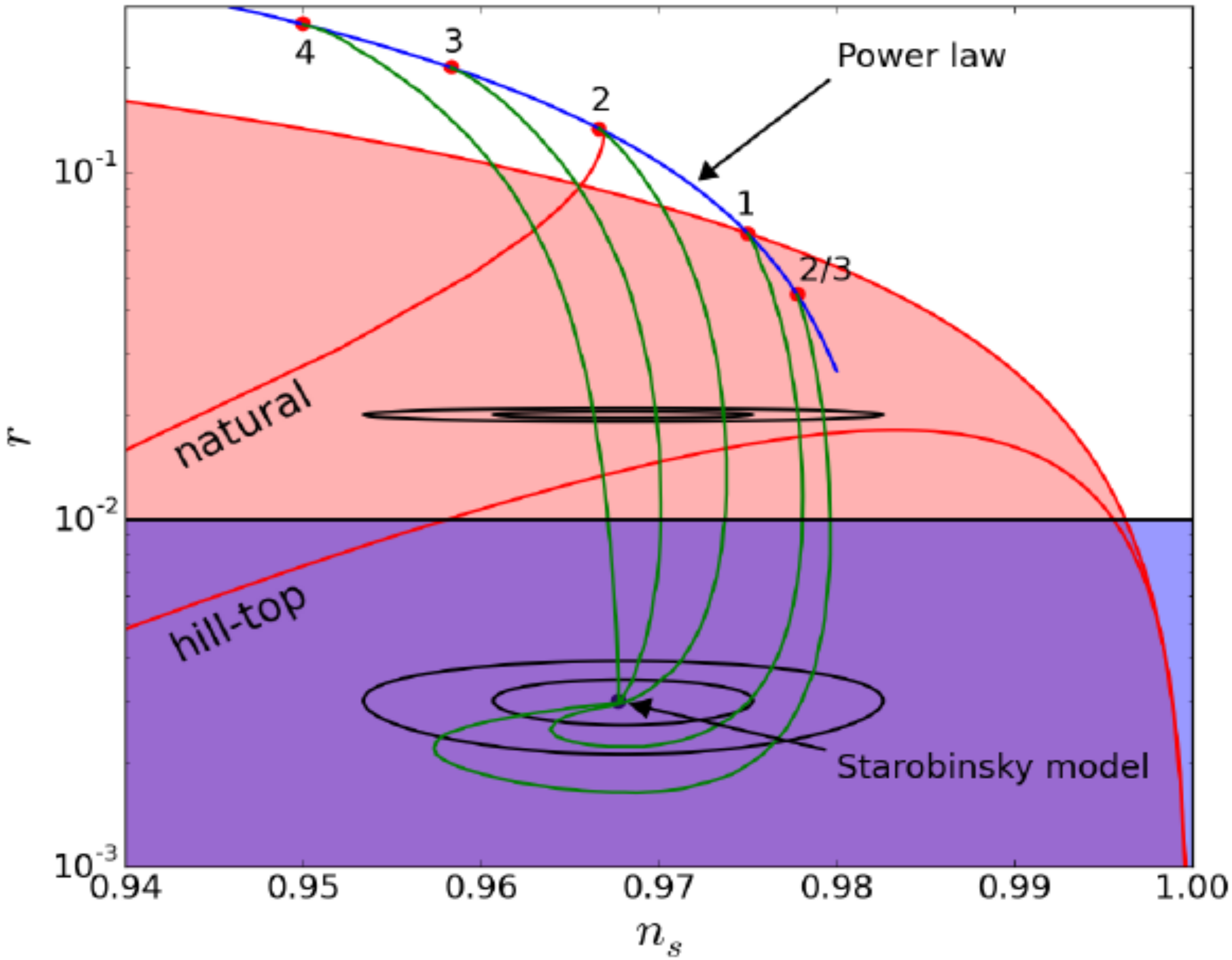




- Multi-band instrument, 15 frequency bands from 40 to 400 GHz
- Two independent telescopes : LFT (40-135 GHz ; 12 bands) and HFT (250-400 GHz, 3 bands)
- Resolution 20’ to 70’
- Cold continuosly rotating Half-wave-plate
- 2622 TES cooled down @ 0.1
- 2 years of operation
- Launch expected for 2026-2027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



LITEBIRD design and expected performance



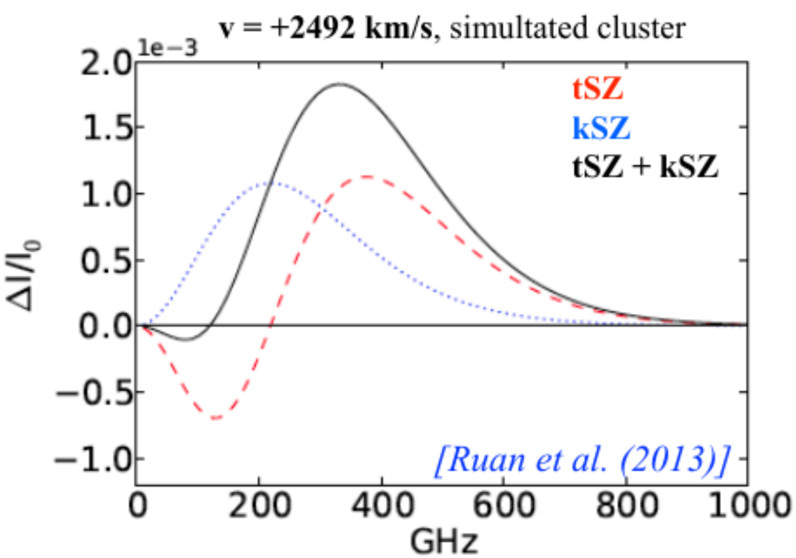
10^{-3} sensitivity in r in 2 years of operation,
good foreground removal, problems with delensing

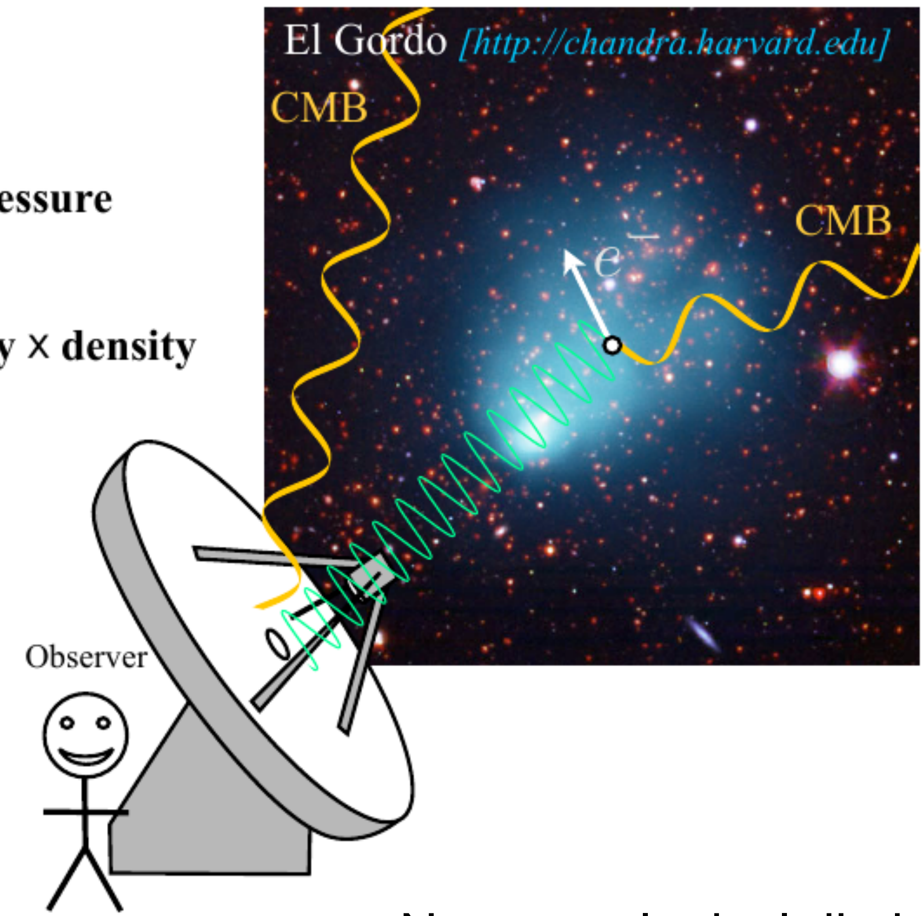
Sunyaev-Zeldovich effect

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

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

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





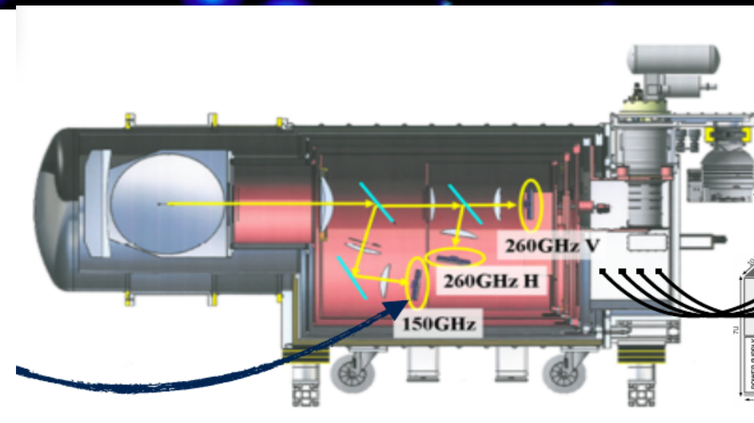
➡ **SZ = probe for intracluster gas**

No cosmological diming

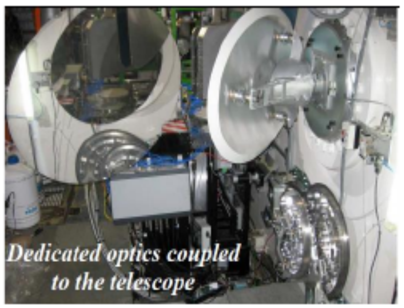
NIKA2: a millimeter camera for cluster cosmology

The NIKA2 camera

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)

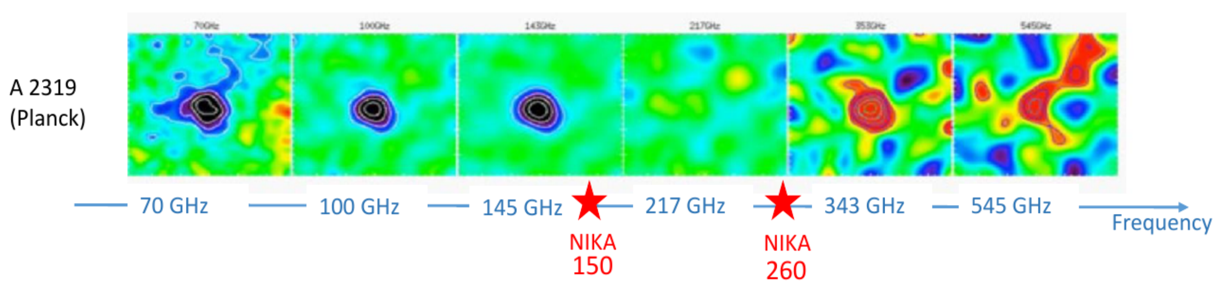
The NIKA2 camera

- 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

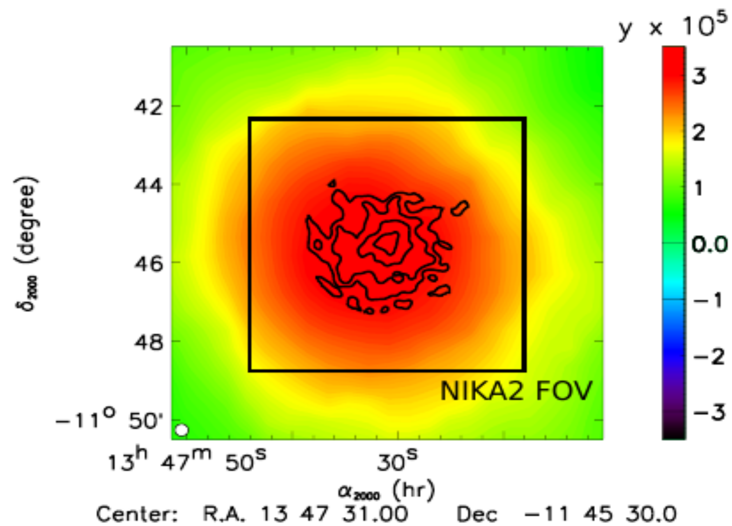
Frequency	150 GHz	260 GHz
# KIDs	616 (553)	2 x 1140 (960)
FOV diameter	6.5 arcmin	6.5 arcmin
Sensitivity	9 mJy/s$^{1/2}$	33 mJy/s$^{1/2}$
Angular res.	17.7 arcsec	11.2 arcsec

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

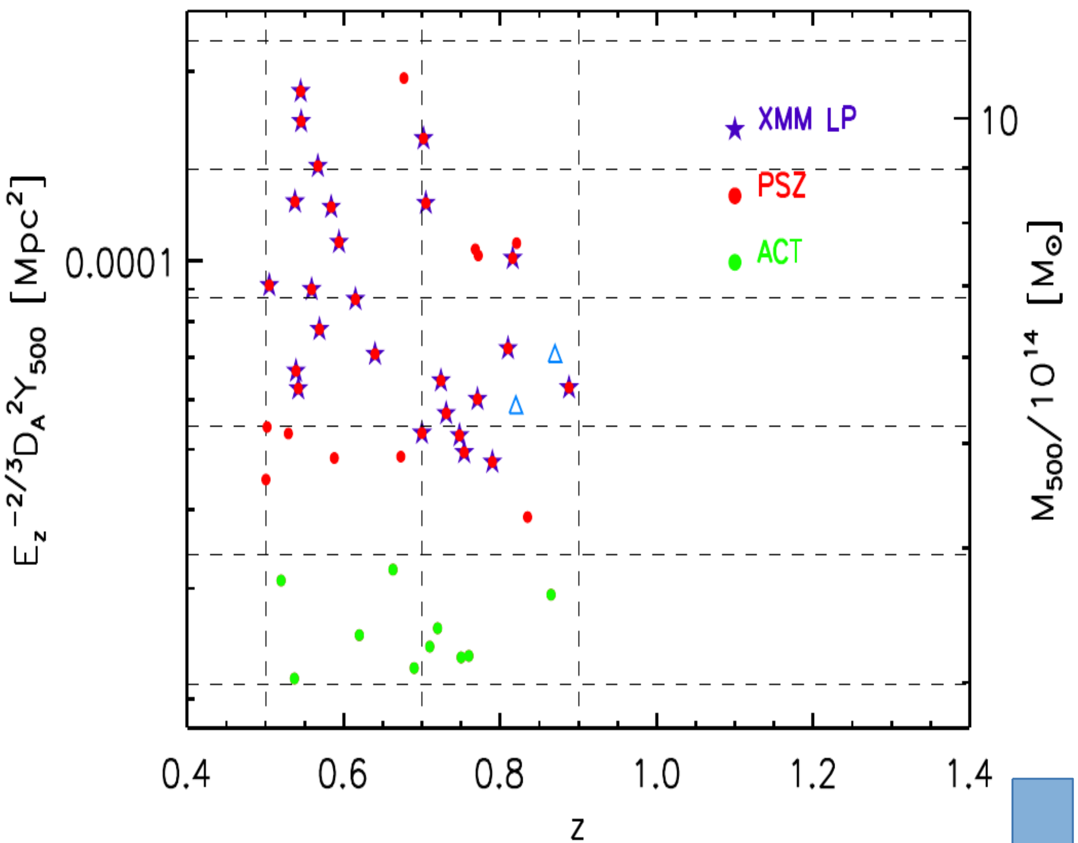
NIKA2 is well adapted for SZ observations of intermediate and high redshift



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



NIKA2 SZ Large program



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:

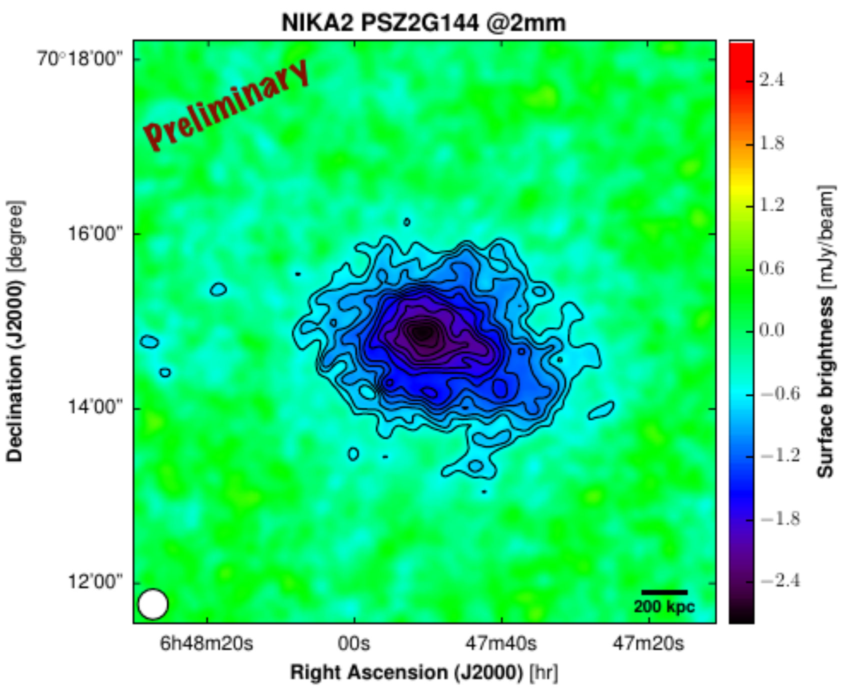
- Dynamical state (mergers)
- Morphology (ellipticity)

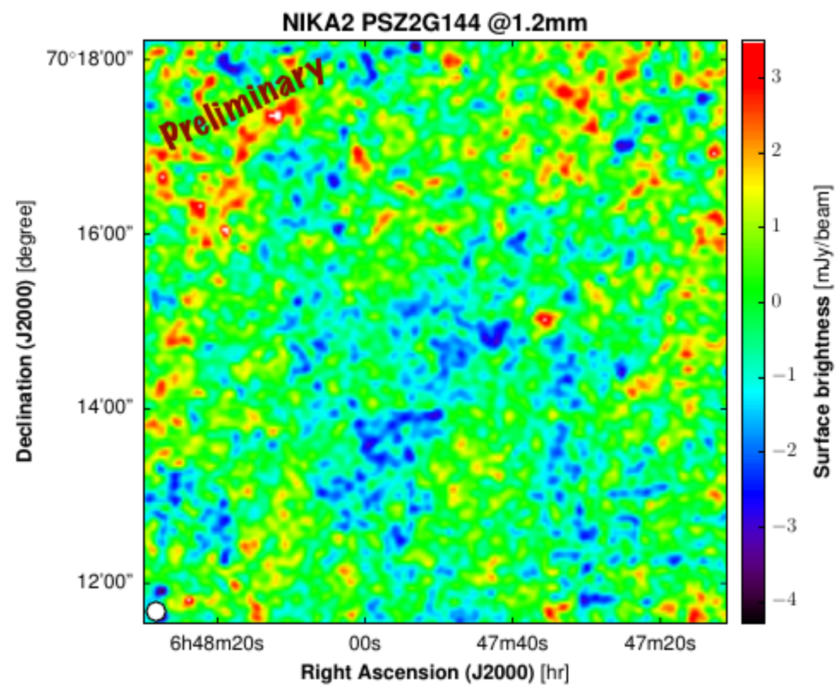
First NIKA2 SZ LP cluster

PSZ2 G144

- Planck tSZ detected cluster at redshift, z = 0.58, high mass $M_{500} = 7.8 \times 10^{14}\ M_{\odot}$
- 11h observations with NIKA1 in poor weather conditions (atmospheric opacity 0.3@225 GHz)
- Already observed: SZ – Mustang & Bolocam, X-rays - XMM

[Ruppin et al, 2018]





Very promising results, detailed analysis on going

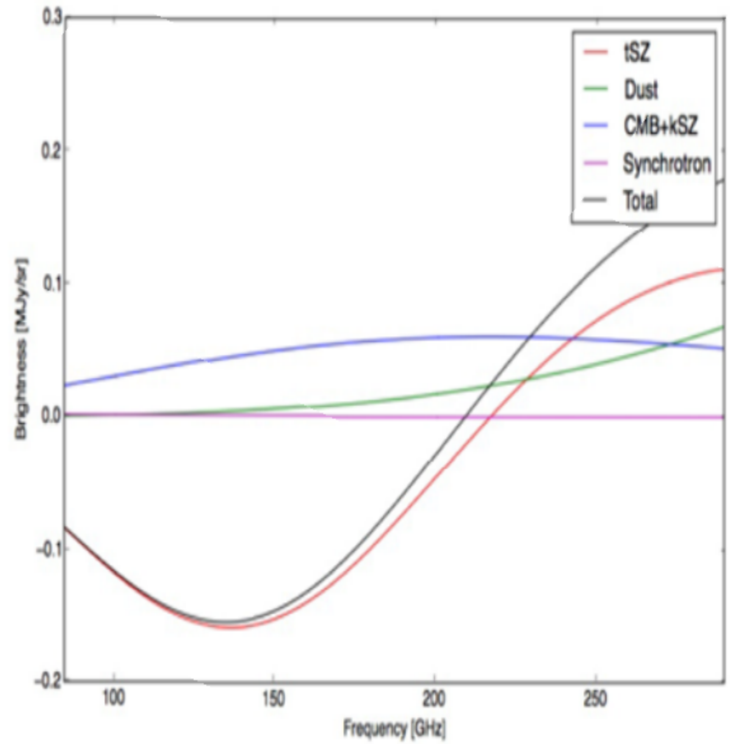
KISS

Kid Imager-Spectrometer Survey

- Grenoble (Institut Néel, LPSC, & IPAG), Tenerife (IAC) & Roma (La Sapienza) collaboration

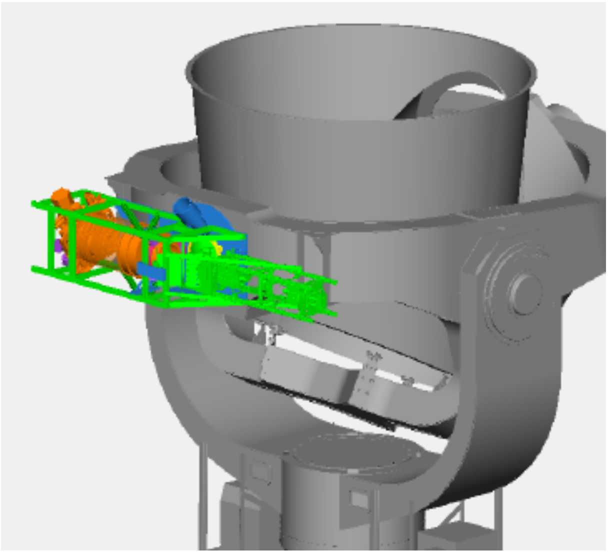
KISS Scientific motivation and concept

- Use low resolution spectroscopy to separate different components in the millimeter emission of clusters
- Map low redshift clusters physical properties from their SZ spectral distorsions : pressure (tSZ), temperature (RtSZ), LOS velocity (kSZ)

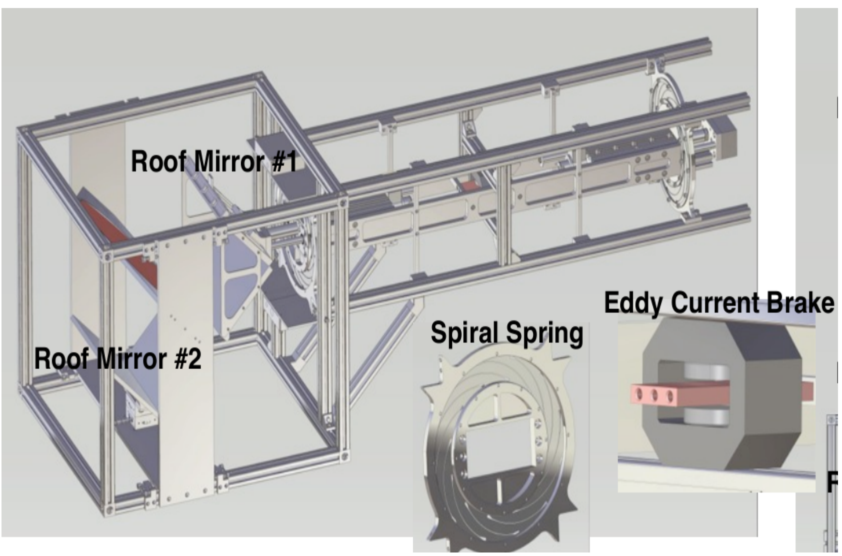


- ***KISS*** : Low-resolution (Δv = 1-3 GHz) Martin-Puplett interferometer spectrometer coupled to a KID based camera (100-300 GHz) mounted at the QUIJOTE telescope (2.25 m diameter) in Teide observatory (Tenerife)

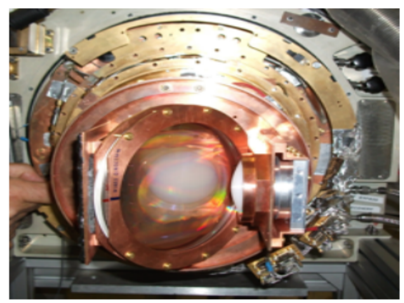
Instrument design and status



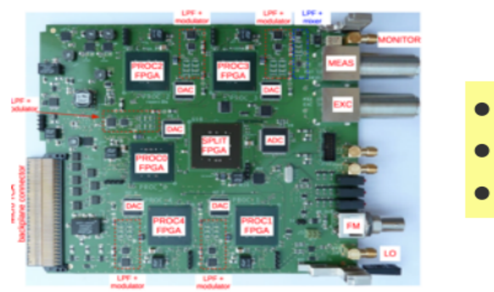
- Telescope ready for operations early 2018
- MPI has been built, currently under test at Grenoble labs
- NIKA camera has been adapted for KISS optical design
- Large frequency band (80-300 GHz) 500 KID arrays has been constructed
- Readout electronic ready for use

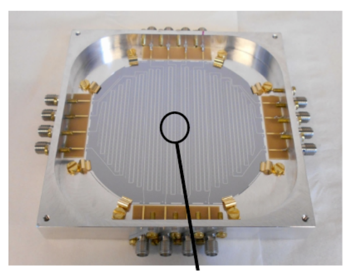


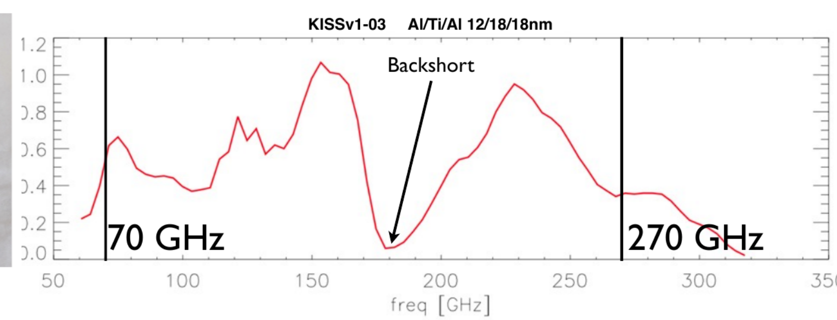
Dilution Cryostat 3He-4He (100 mK)



Frequency Multiplexing Read-Out Electronics : NIKEL







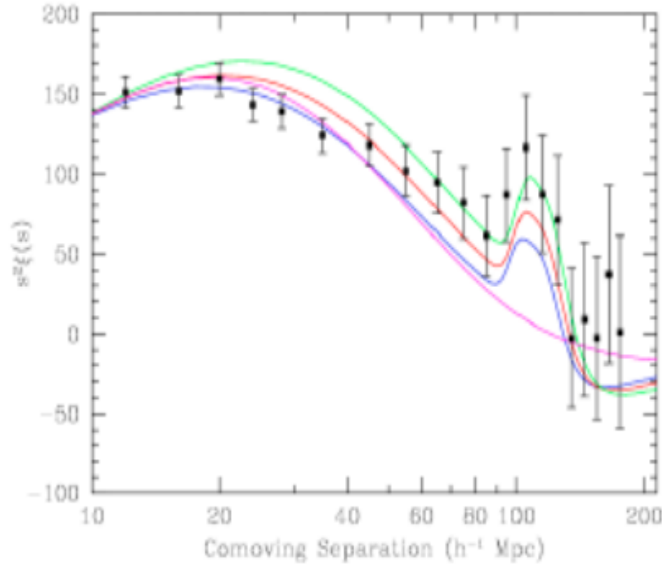
KISS Specifications and observation strategy

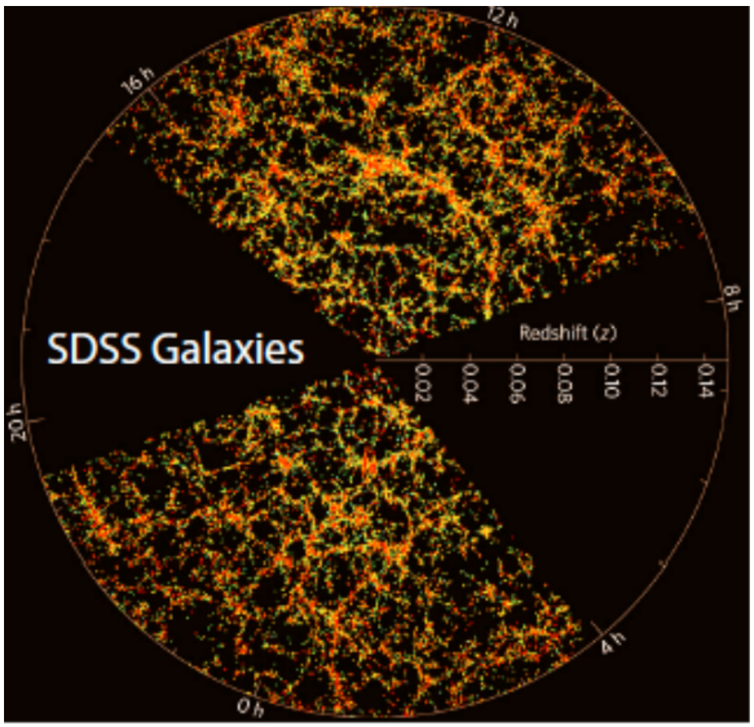
Telescope diameter [m]	2.5
Resolution [arcmin]	from 5 to 1.7
FOV [degrees]	1
Number of detectors	600
Frequency range [GHz]	80 - 280
Number of frequency bins	up to 200
Spectral resolution [GHz]	1-10
Modulation [Hz]	1-10
NEP [W /Hz$^{1/2}$] BLIP	4.35 10^{-16}
NEFD [mJy/Hz$^{1/2}$] BLIP	68
NEFD per frequency bin [Jy/Hz$^{1/2}$] BLIP	1.44

- Astrophysical targets :
  - Low redshift clusters from Planck tSZ catalogue
  - Planet and bright radio sources for spectral calibration
- Atmospheric emission correction :
  - 5 interferograms per second to avoid atmospheric variations
  - Hardware instantaneous subtraction of atmospheric background
  - Filter out atmospheric absorption bands

- More work in simulations and data anlaysis is in progress

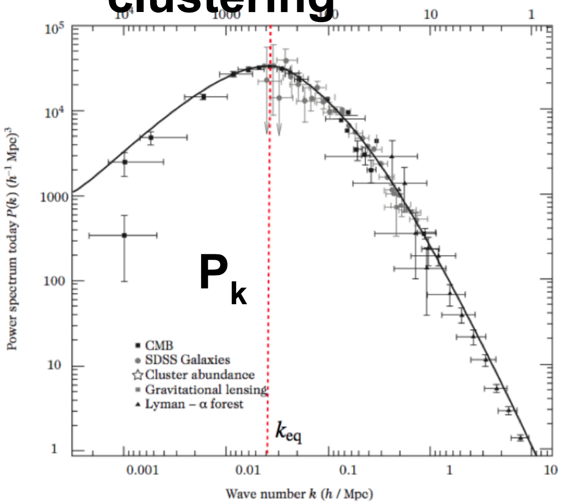
Part II :
LSS OBSERVATIONS

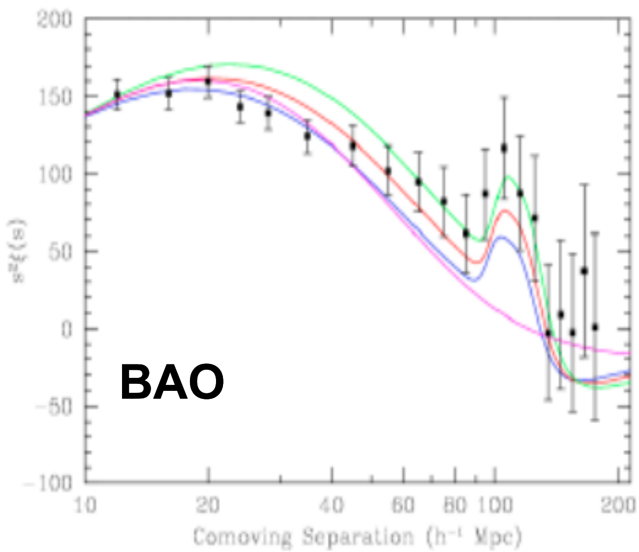




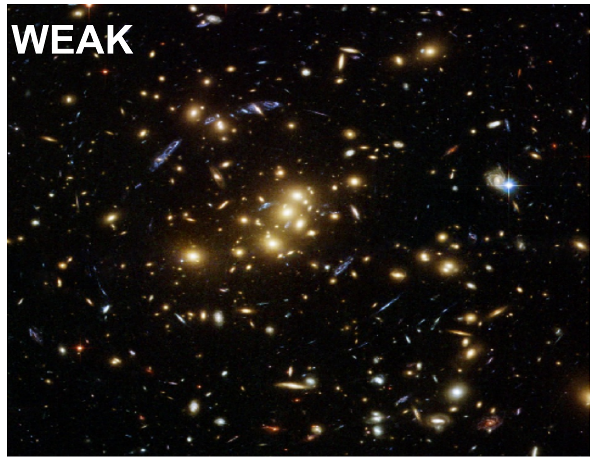
LSS observables

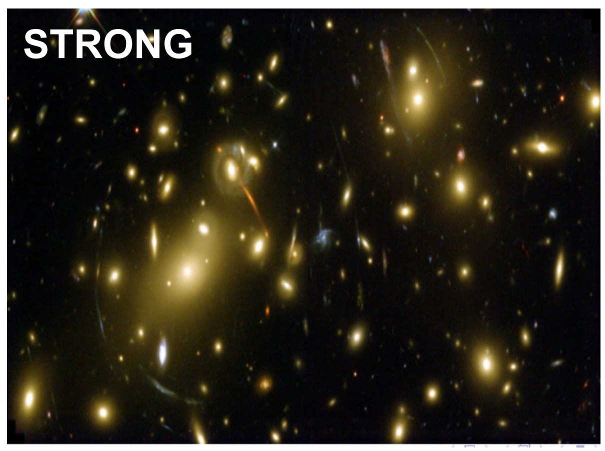
- **Galaxy clustering**



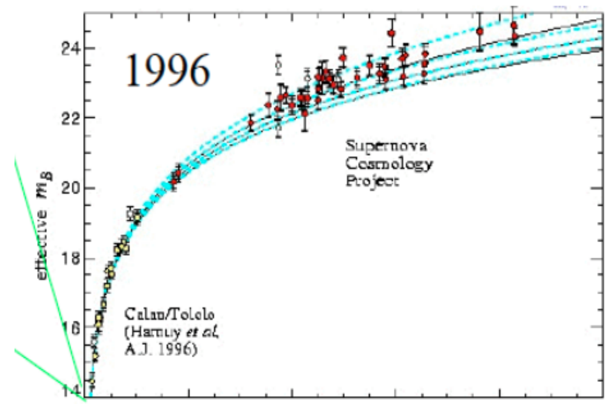


- **Lensing : weak & strong**

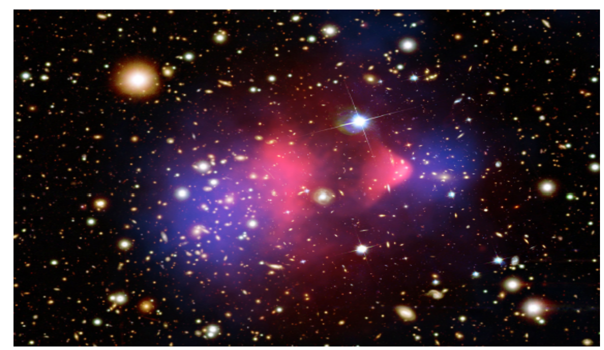


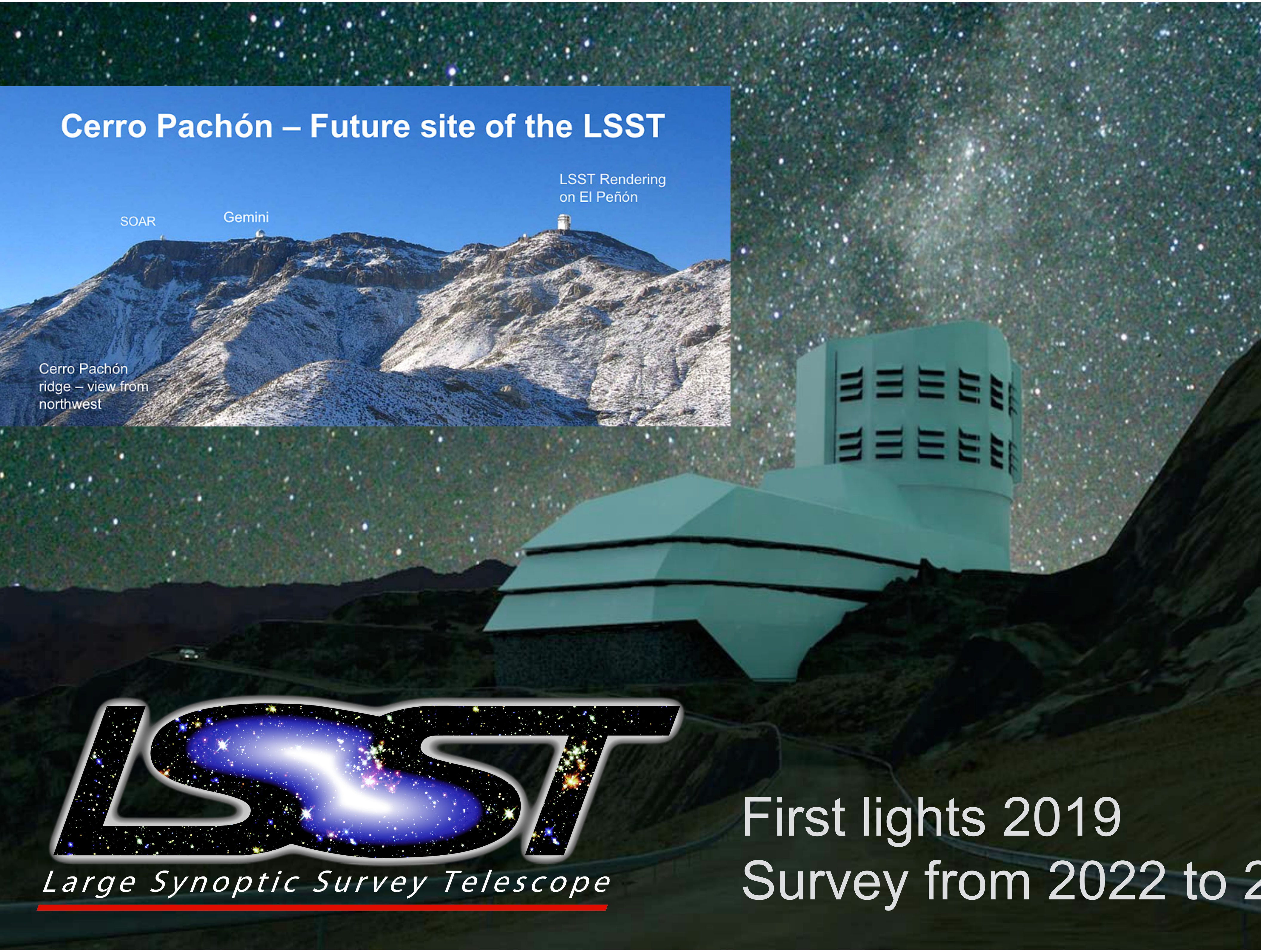


- **Supernovae type I**



- **Clusters of galaxies**




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 2019
Survey from 2022 to 2

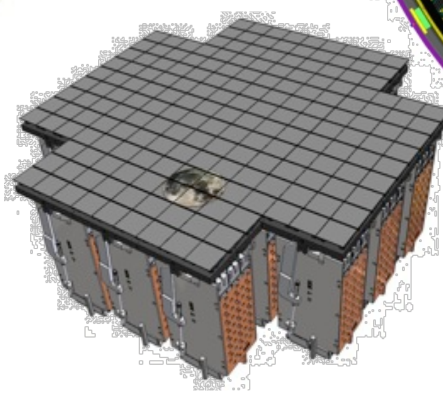
Cerro Pachón, Chili (2715 m d’altitude)

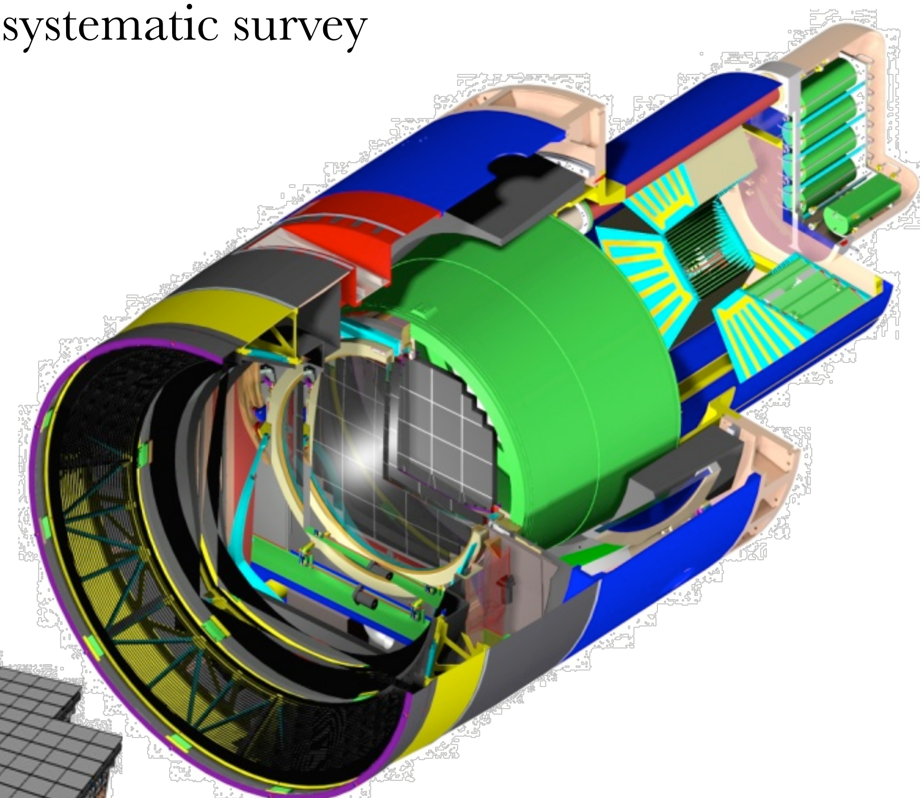
Mars
2011

26 septembre 2017

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

Large = big
Synoptic = view all
Survey = systematic survey

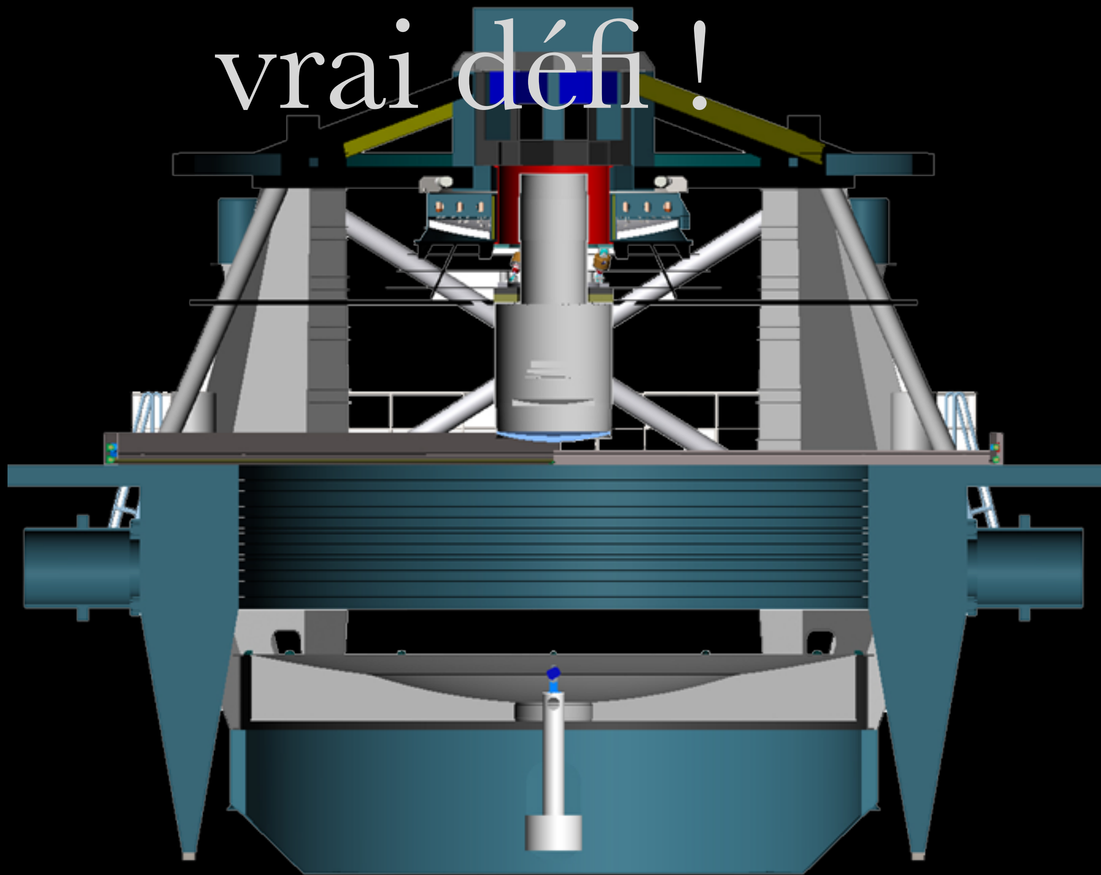


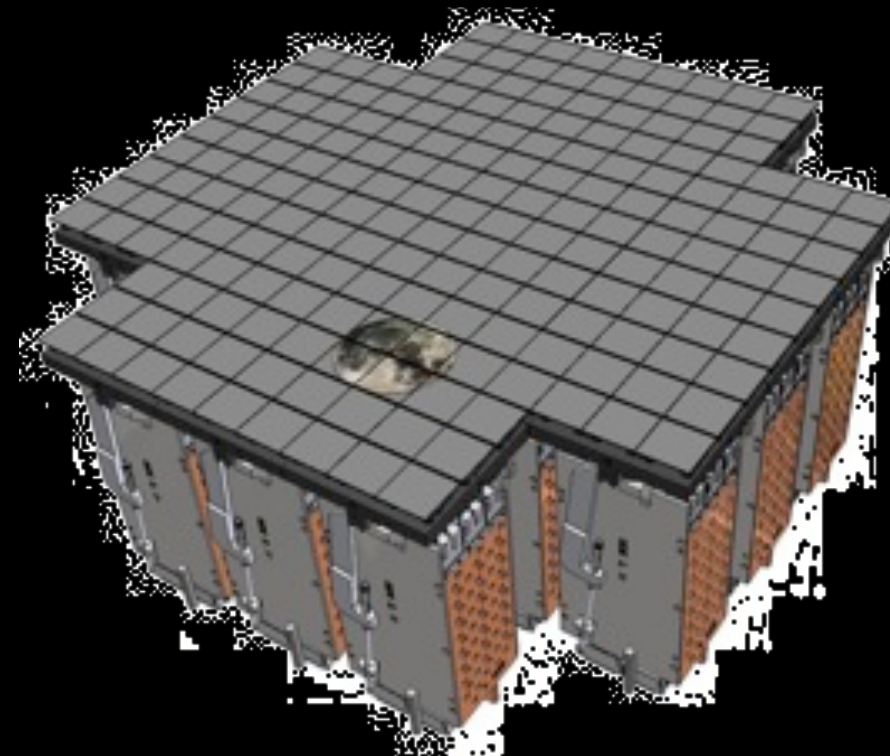


8.4 m diameter telescope to be able to detect faint objects

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

Profond, large & rapide : un vrai défi !

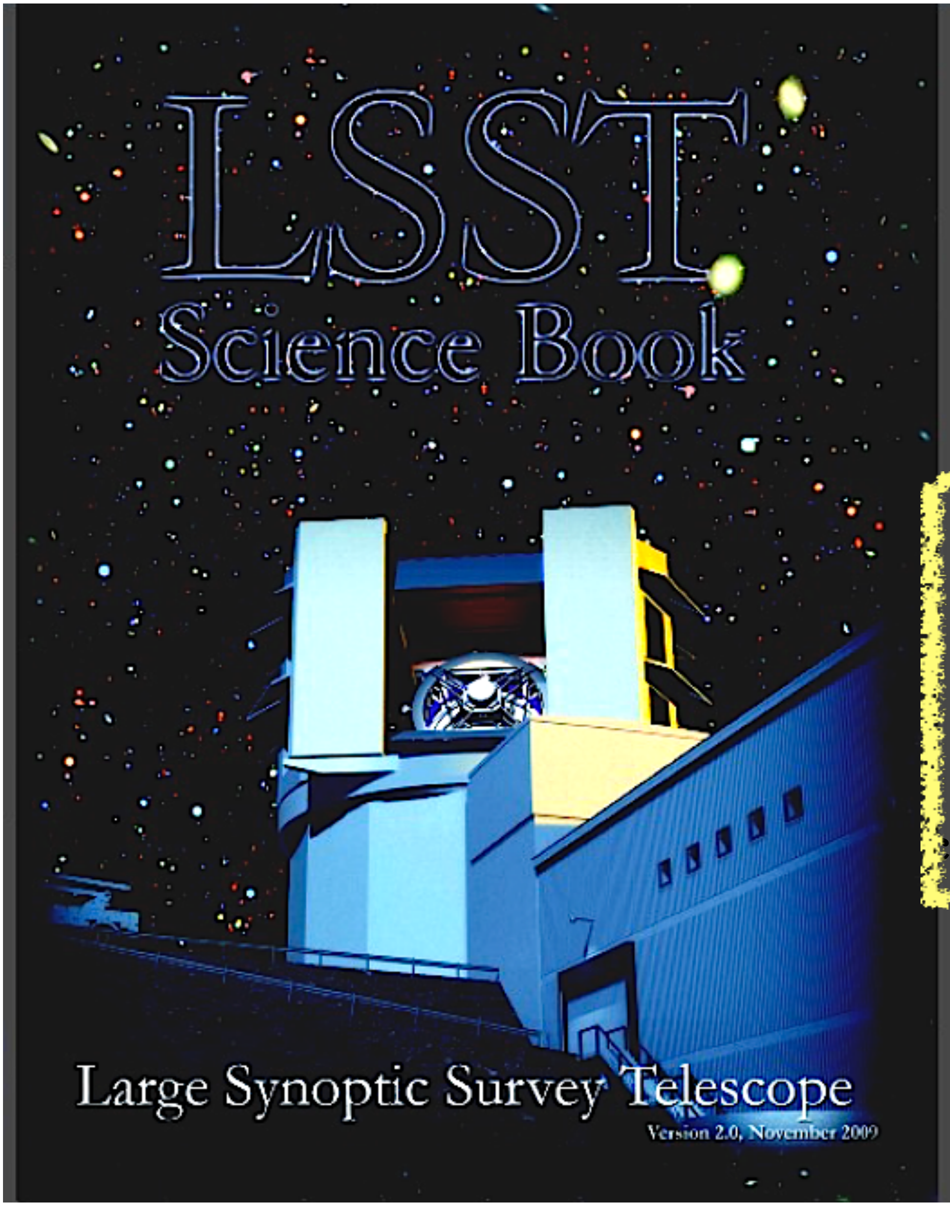




Une structure mobile de 300 tonnes, compacte pour

3 milliards de pixels pour observer un large champ de vue, électronique de lecture rapide (2 secondes) pour optimiser

LSST scientific program



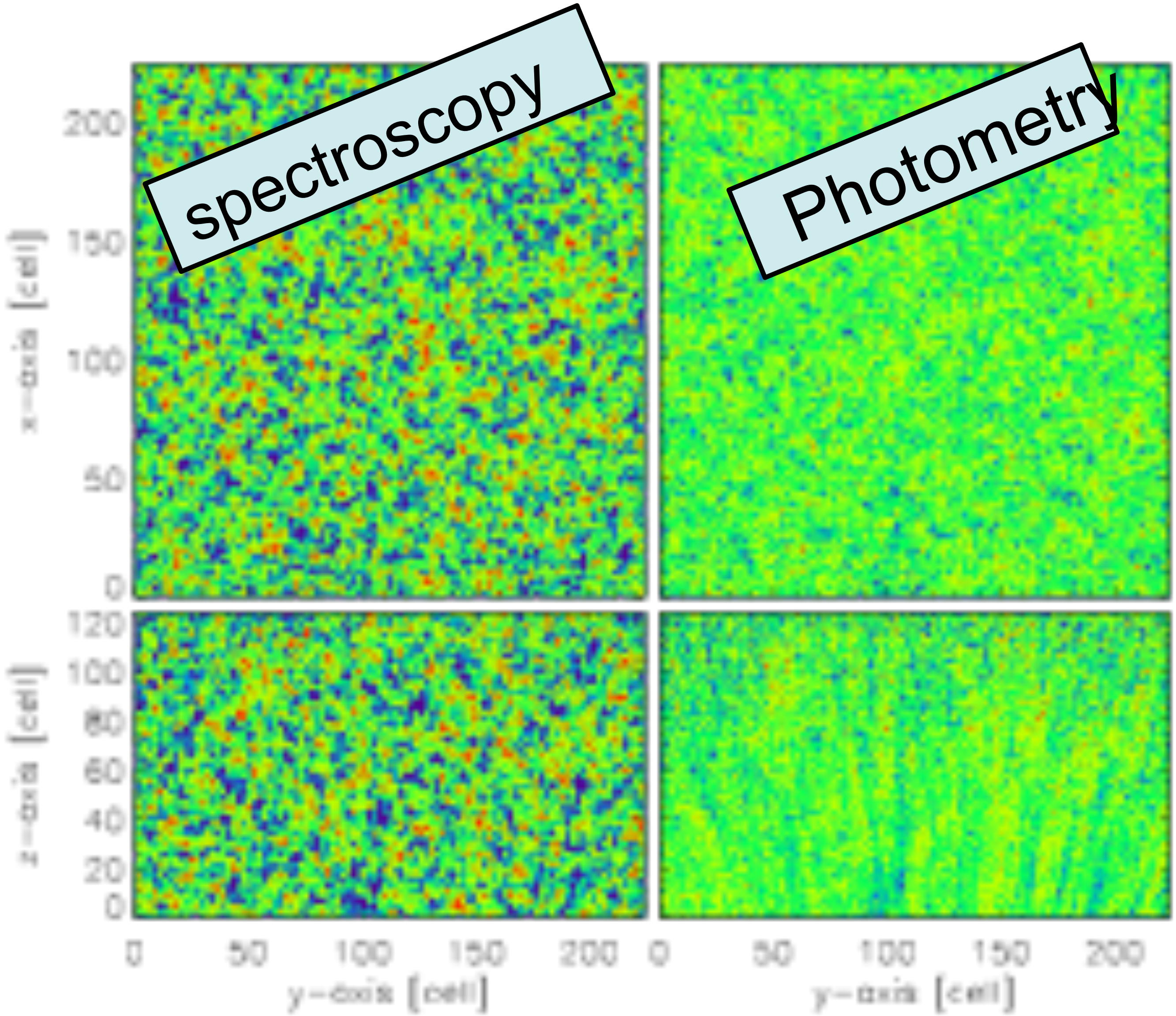
www.lsst.org/lsst/scibook

- ➔ 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

osmologie

IN2P3 labs are fully involved in cosmological studies

Mesure the position of milliards of galaxies



To use galaxies for cosmology we need to measure their redshift

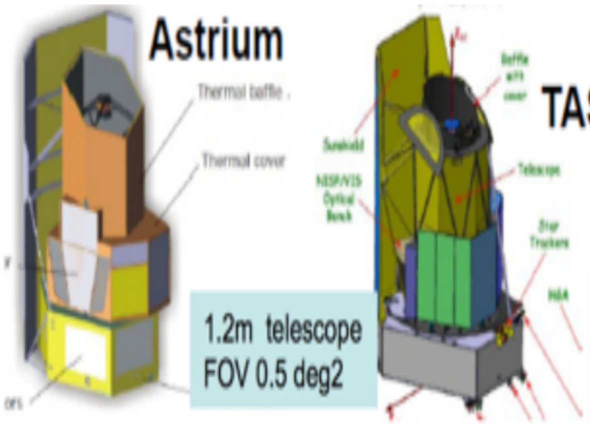
Accurate photometry in 6 bands = very low resolution spectroscopy

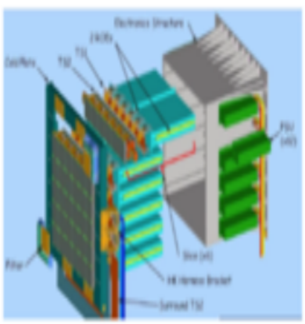
Need to estimate redshift for 3-4 milliards for galaxies up to z=2-3

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

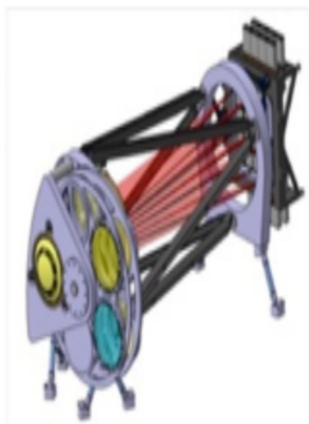
EUCLID

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

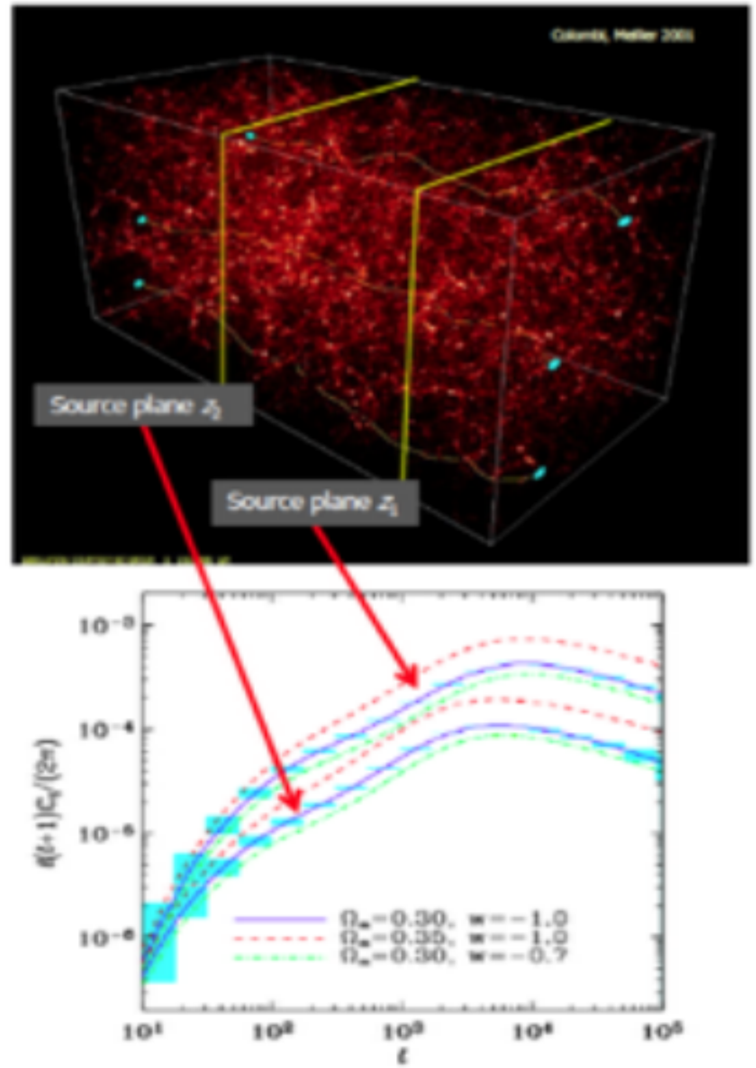
- M class ESA space mission
- All-sky visible and IR observations in photometry and spectroscopy
- Exposure depth 24 magnitudes
- 2 surveys : shallow (15000 deg^2), deep (2 x 20 deg^2)
- Consists of 2 channels, and 3 instruments :
  - VIS, optical imager for lensing reconstruction (550-900 nm)
  - NISP,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

EUCLID cosmological probes

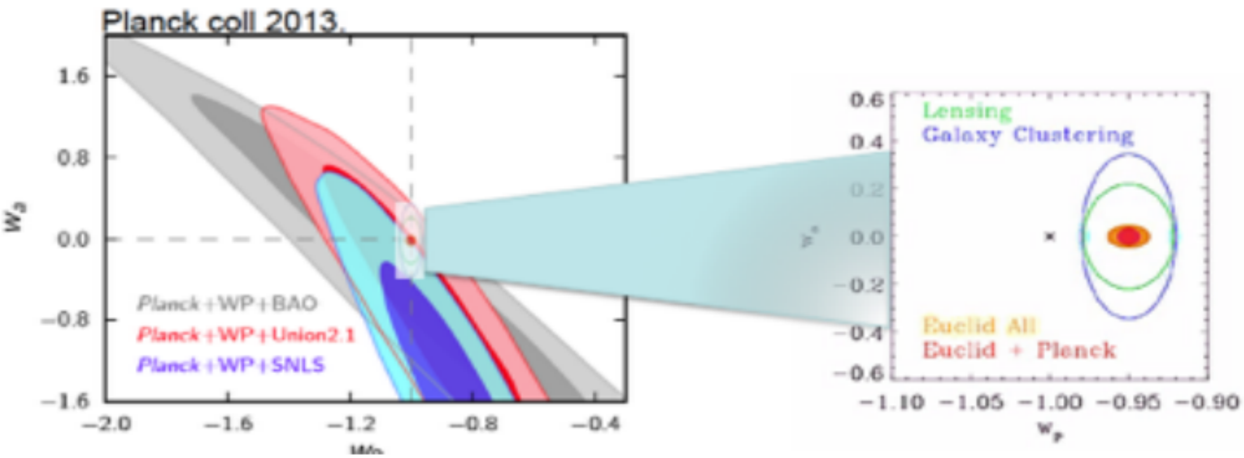
Weak lensing (WL)
- distribution of matter, expansion history, growth rate, tomography
- 3-D cosmic shear measurements 0 < z< 2
- shape and photo-z from optical and NIR data
- 1.5 billion galaxies

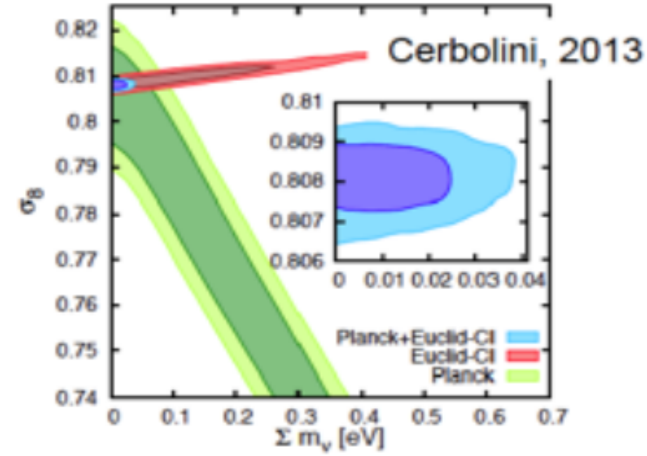
Galaxy clustering (GC)
- distribution of matter, expansion history, growth rate, tomography
- 3-D position measurements 0.7 < z< 2
- 3D distribution of galaxies from spectroscopy redshift
- measure position of 50 millions galaxies

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