QUBIC-Project: a new "look" at the cosmic background radiation

Beatriz García on behalph of QUBIC Argentina

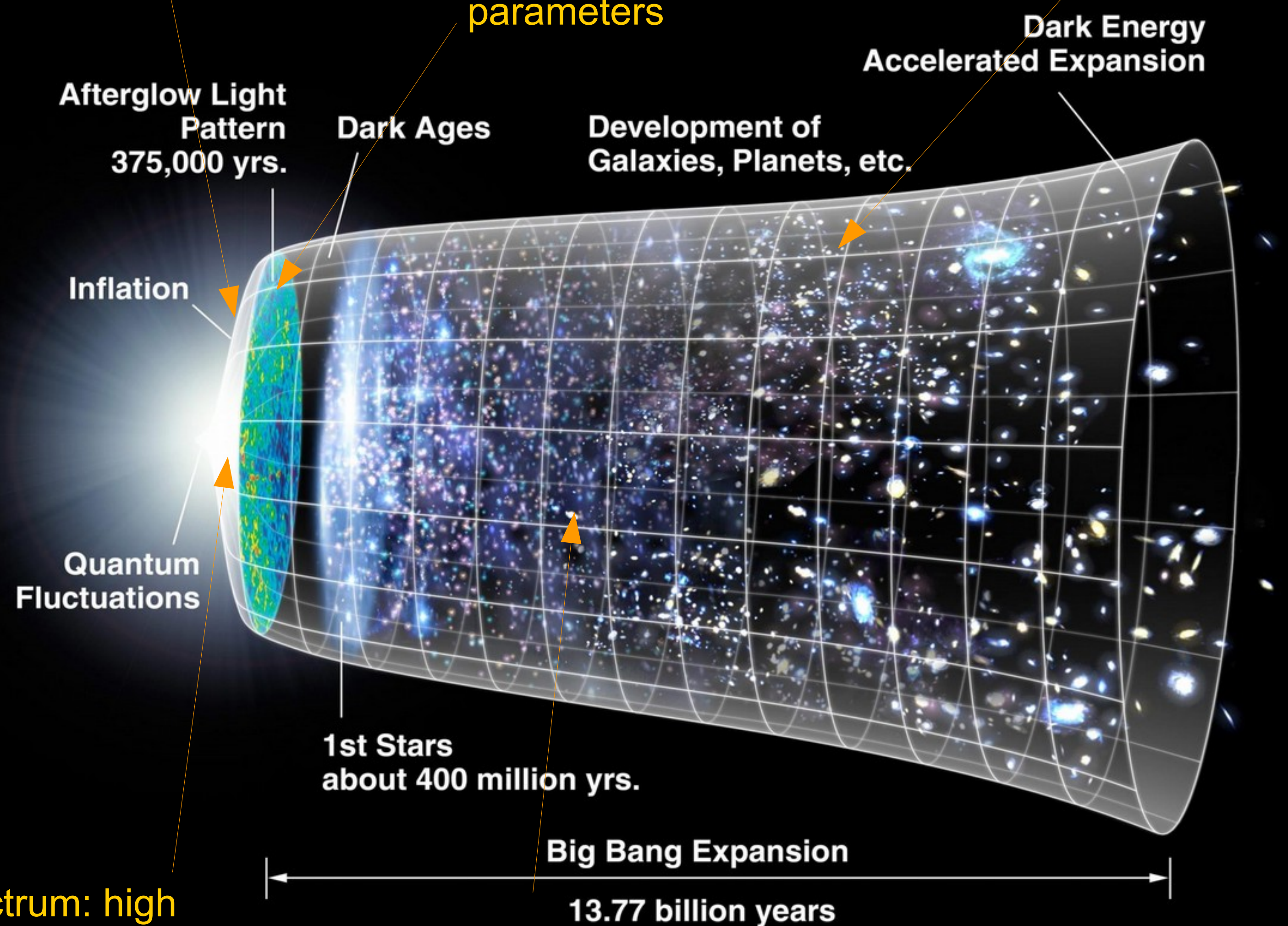
II Latin American Strategy Forum for Research Infrastructure:
an Open Symposium for HECAP

July 6-10, 2020 (by videoconference), ICTP-SAIFR, São Paulo, Brazil

5.te spectrum and polarization mode B measurement. Study of the inflation process at ultra-high energies (10^{19} GeV)

2. Map of primary anisotropies and E modes of polarization of the CMB: Study of oscillation of the primordial plasma, cosmological parameters

3. Estudio de cúmulos de galaxias (todos los cúmulos con M > 10^{14} Ms inside our horizont)



Why we need to measure the CMB?

1. Spectrum: high temperature test of the big bang. Spectral distortions: proof of the time before recombination

4.CMB lens effect: Map of gravitational potential all the way toz = 1100

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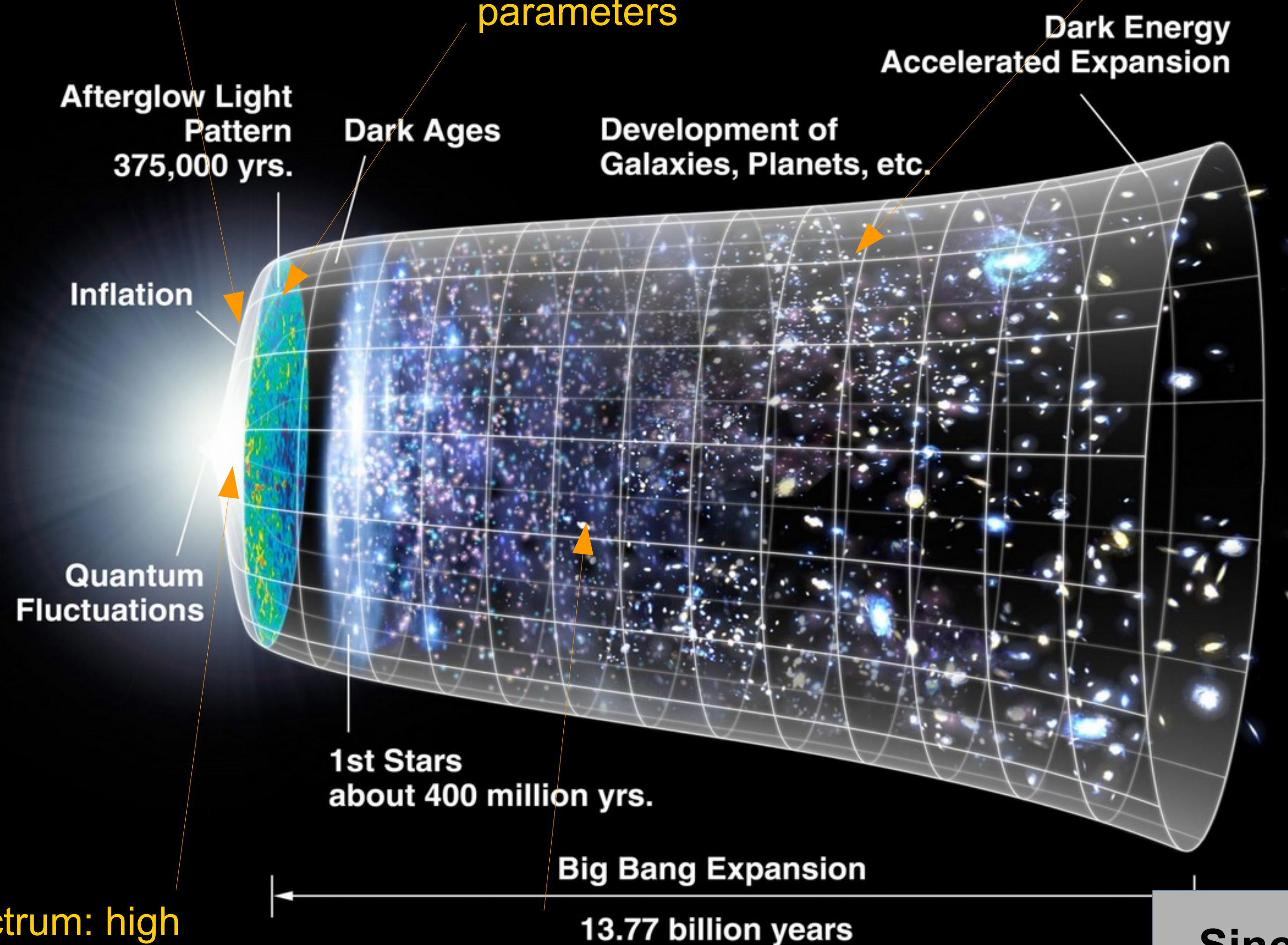

Why we need to measure the CMB?

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Since 1965 CMB measurements have been important

The beginning

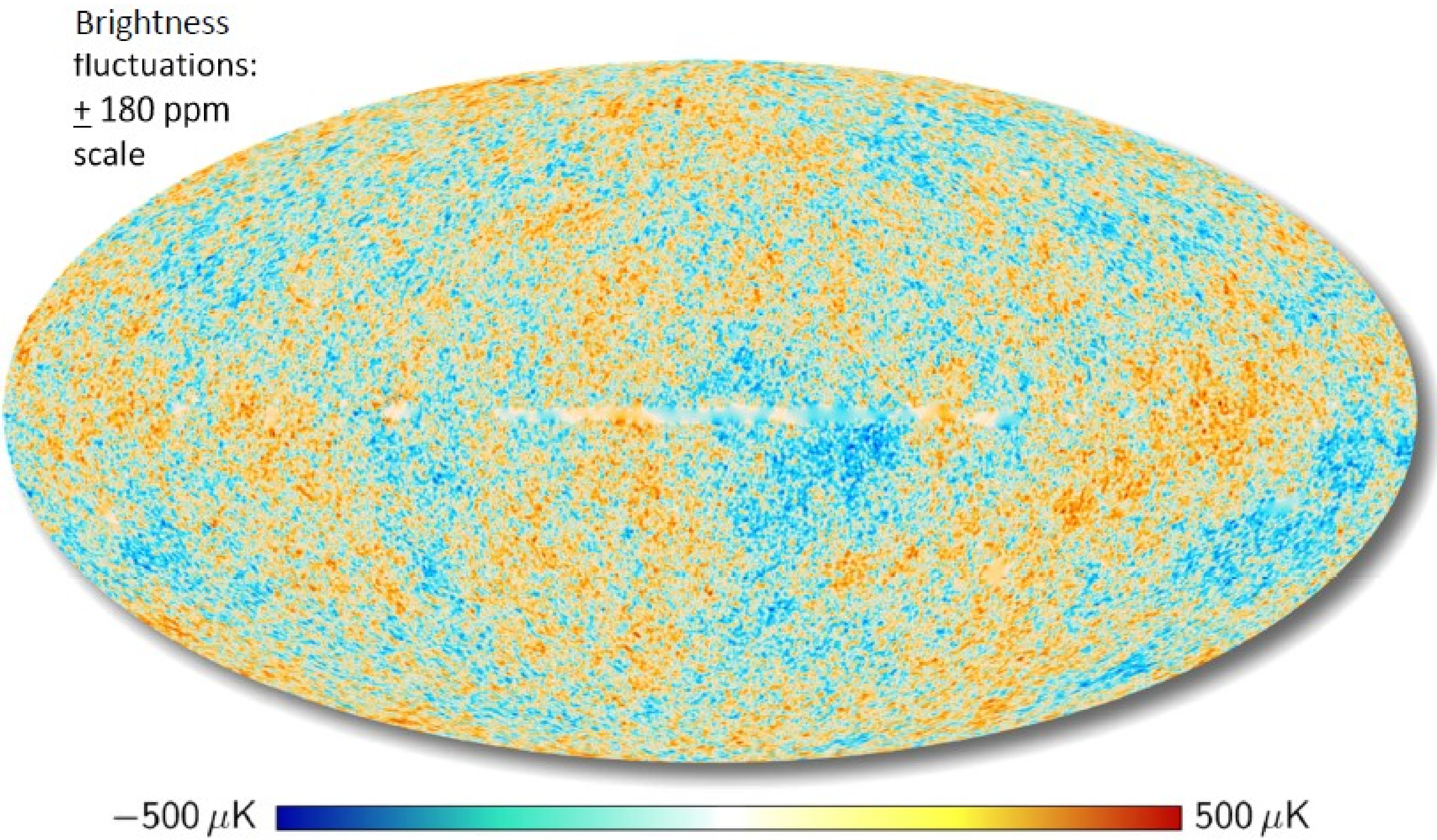
As for the initial moments of the history of the universe (~10^{-38} sec), the observational data is consistent with the "Inflation" paradigm. For a small fraction of a second after the Big Bang, the universe seems to have expanded exponentially, faster than usual. This scenario explains:

- Why does the universe seem to have no curvature? (flat).
- Why is it isotropic?
- Why are there structures in the Universe?
- Why don't we find cosmic relics like magnetic monopoles?

Although inflation convincingly explains these puzzles, we have no direct evidence of it.

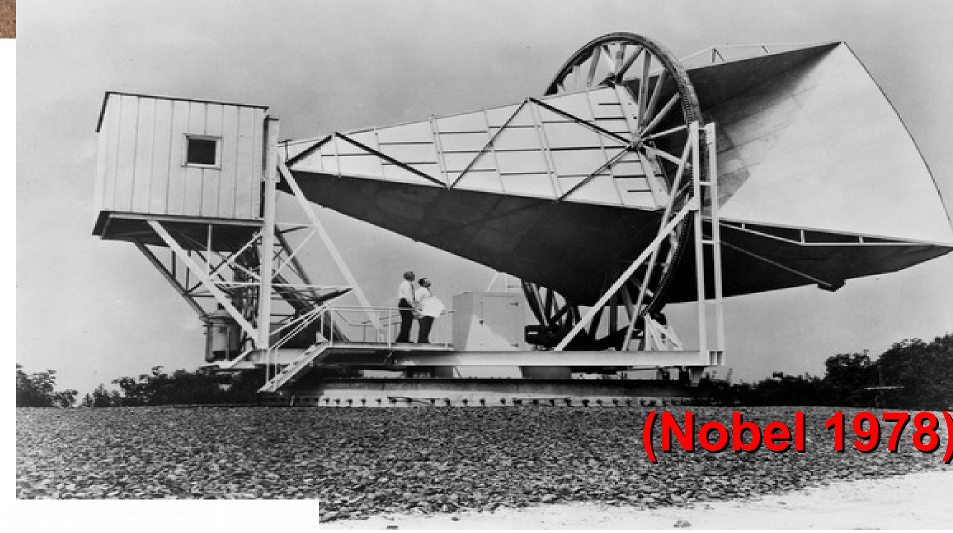
CMB Anisotropies
Planck results

One of the most important predictions of inflation is that above density anisotropies (scalar disturbances of the metric), the production of gravitational waves (tensor disturbances in the metric) is expected.



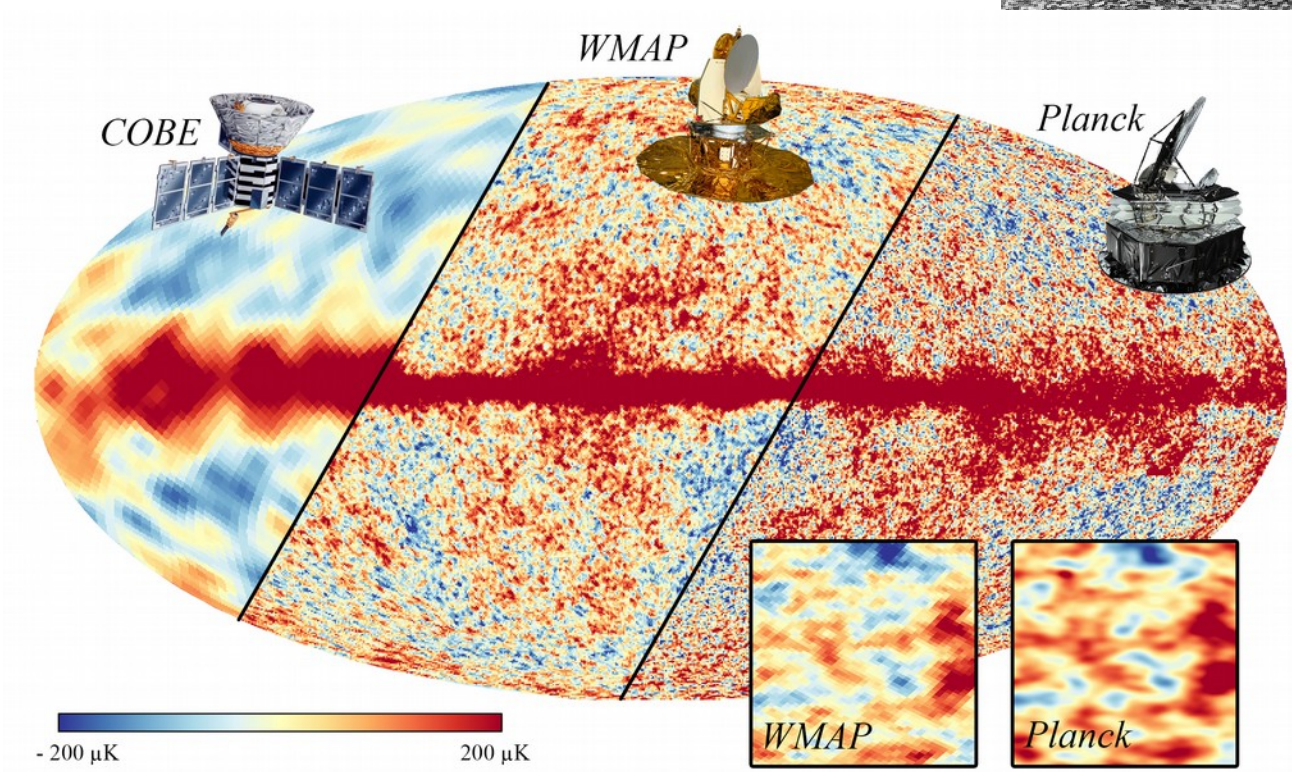
Brief history of the CBM

1964: Penzias-Wilson. Descubrimiento T ~ 3 K



(Nobel 1978)

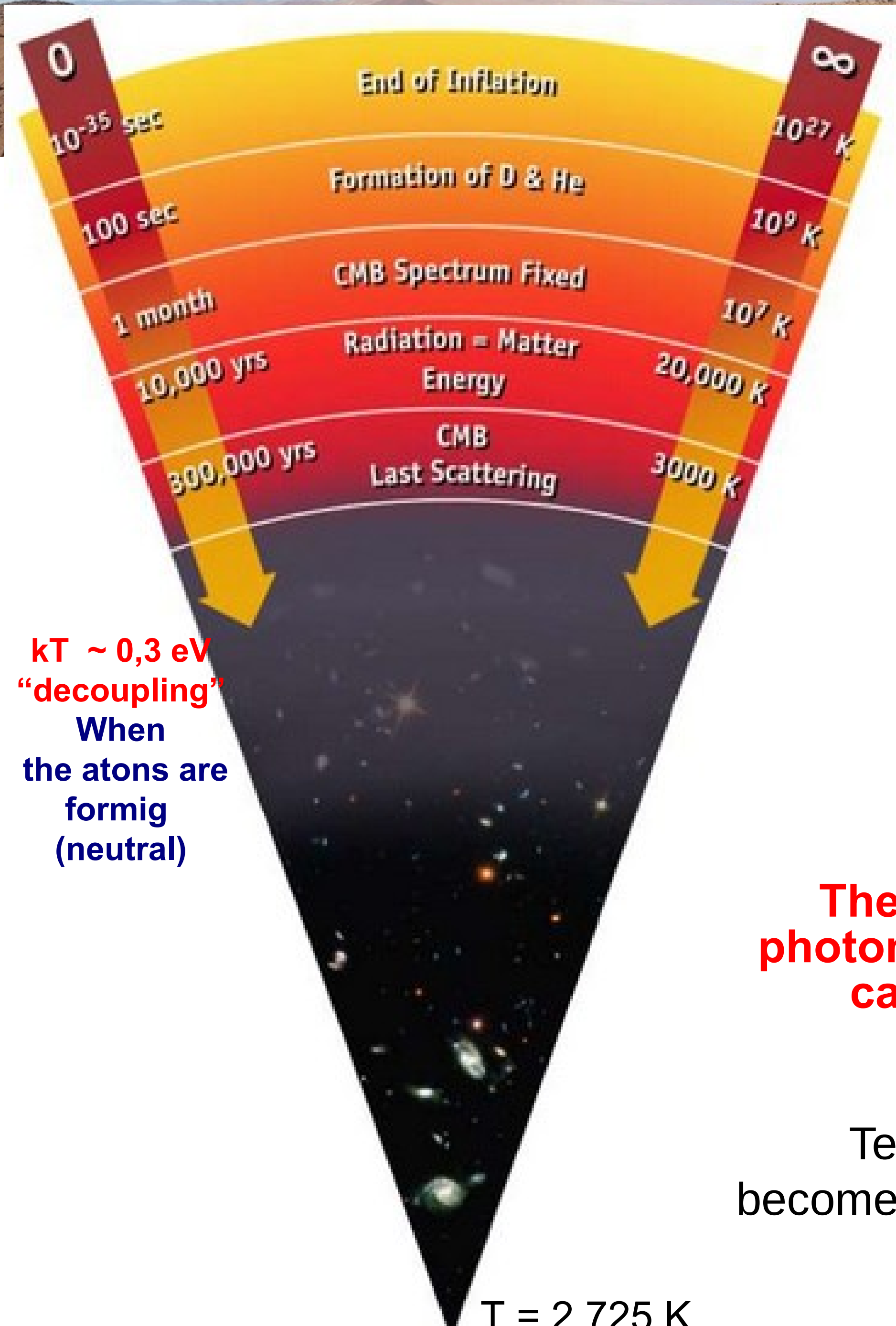
1948: Gamow–Alpher–Herman
Primordial Nucleosyntesis He/H
requires ~ 10^9 photons per nucleon
(prediction: T ~ 5 K)



1992: COBE satellite.
First detection of
Anisotropies “primordiales”
(Nobel 2006)

2013: Planck satellite
Precise measurements of
anisotropies

Decoupling

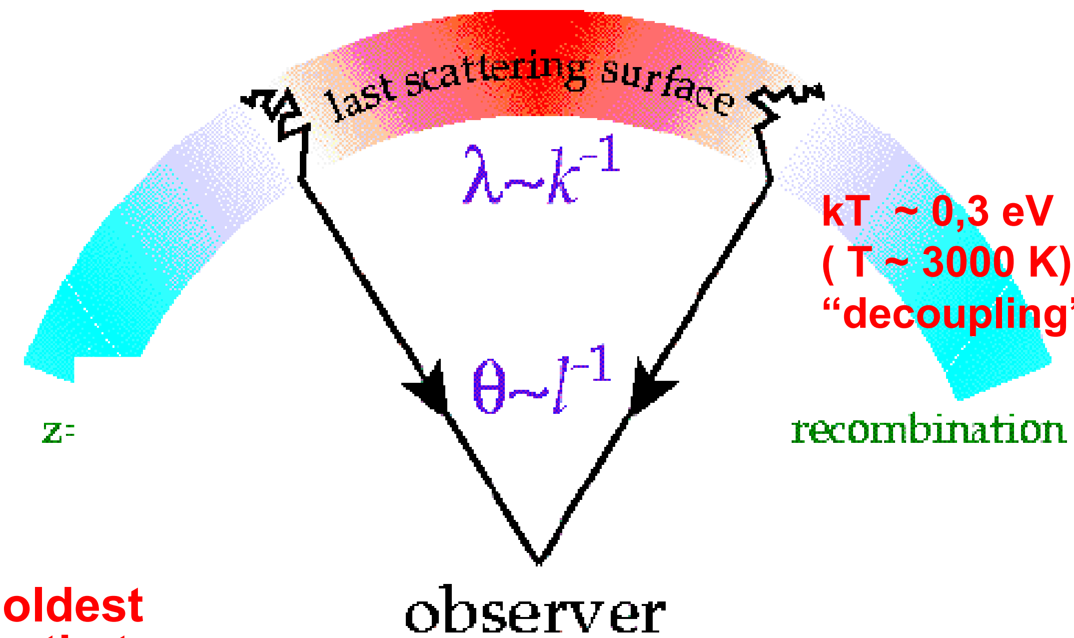


kT ~ 0,3 eV
"decoupling"
When the atons are formig (neutral)

T = 2.725 K

kT >> 13,6 eV

Thomson scattering: Very efficient
(strong coupling between photons, free electrons and protons)



kT ~ 0,3 eV
(T ~ 3000 K)
"decoupling"

The oldest photons that we can see

T = 2.725 K $\Delta T = 50\ \mu K$

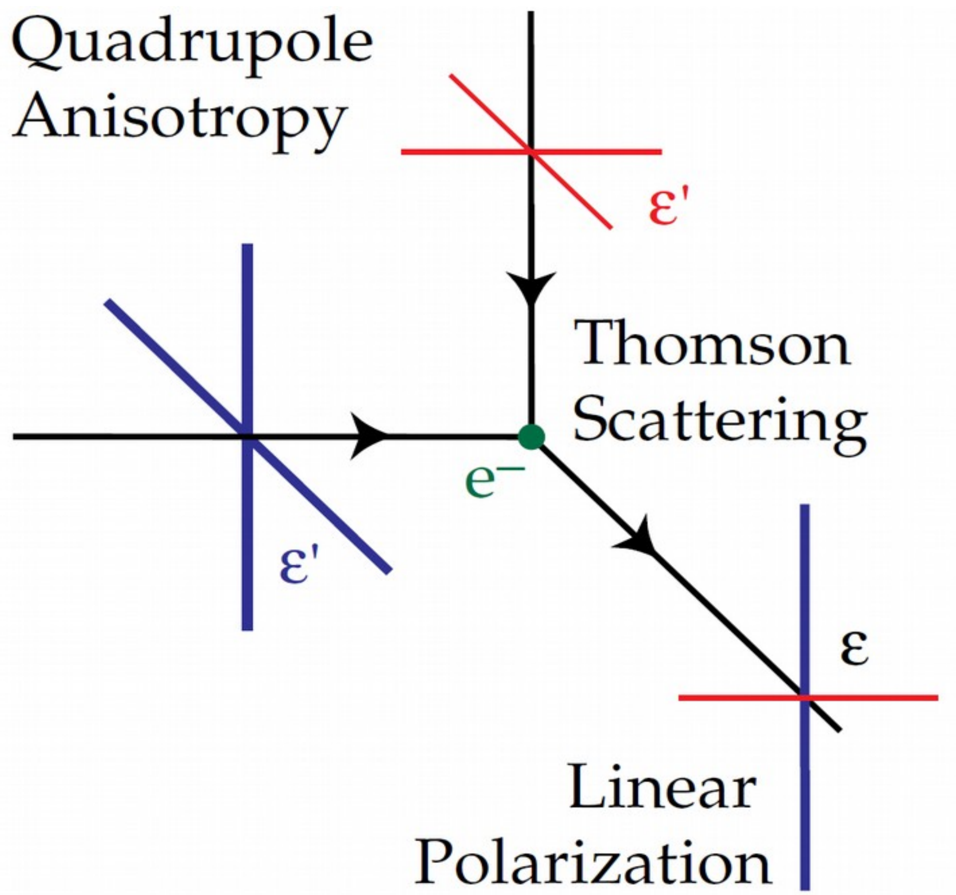
Temperature inhomogeneities at recombination become anisotropy, and that they later formed galaxies

CMB-Polarization

CMB photons are scattered during recombination.

- Thomson scattering, any quadrupole anisotropy in incoming photons produces a degree of linear polarization in scattered photons.

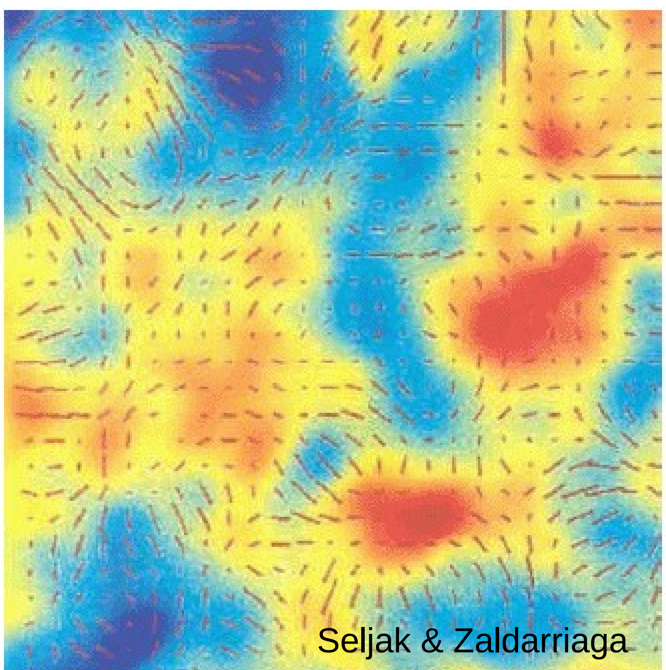
- Perturbations in density produce a small degree of polarization (E modes)

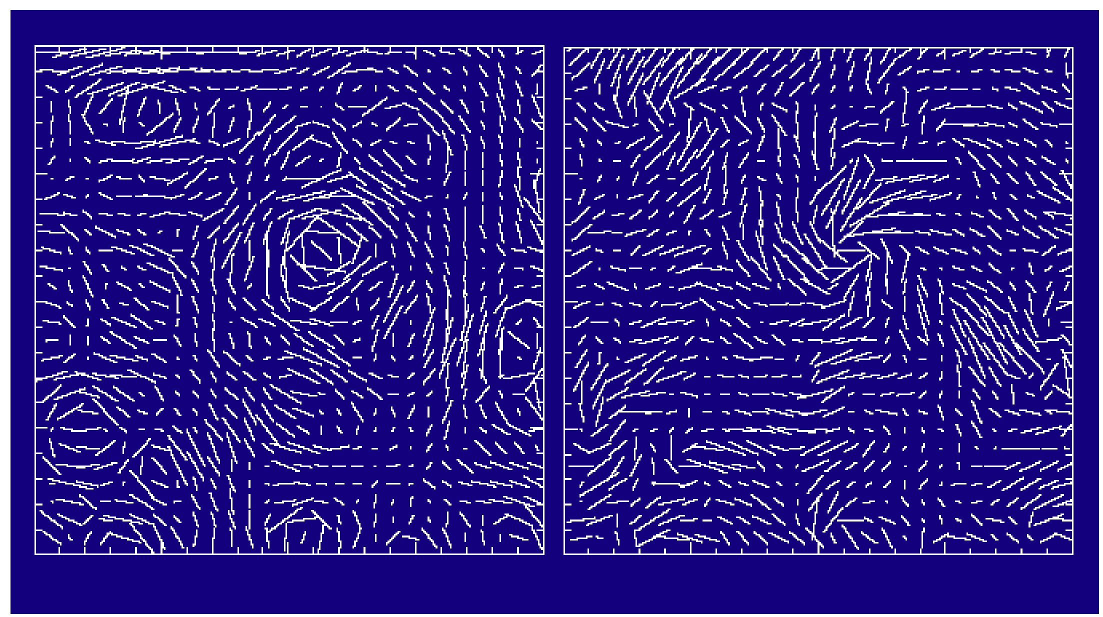


CMB polarization consists in 2 components
of opposite parities

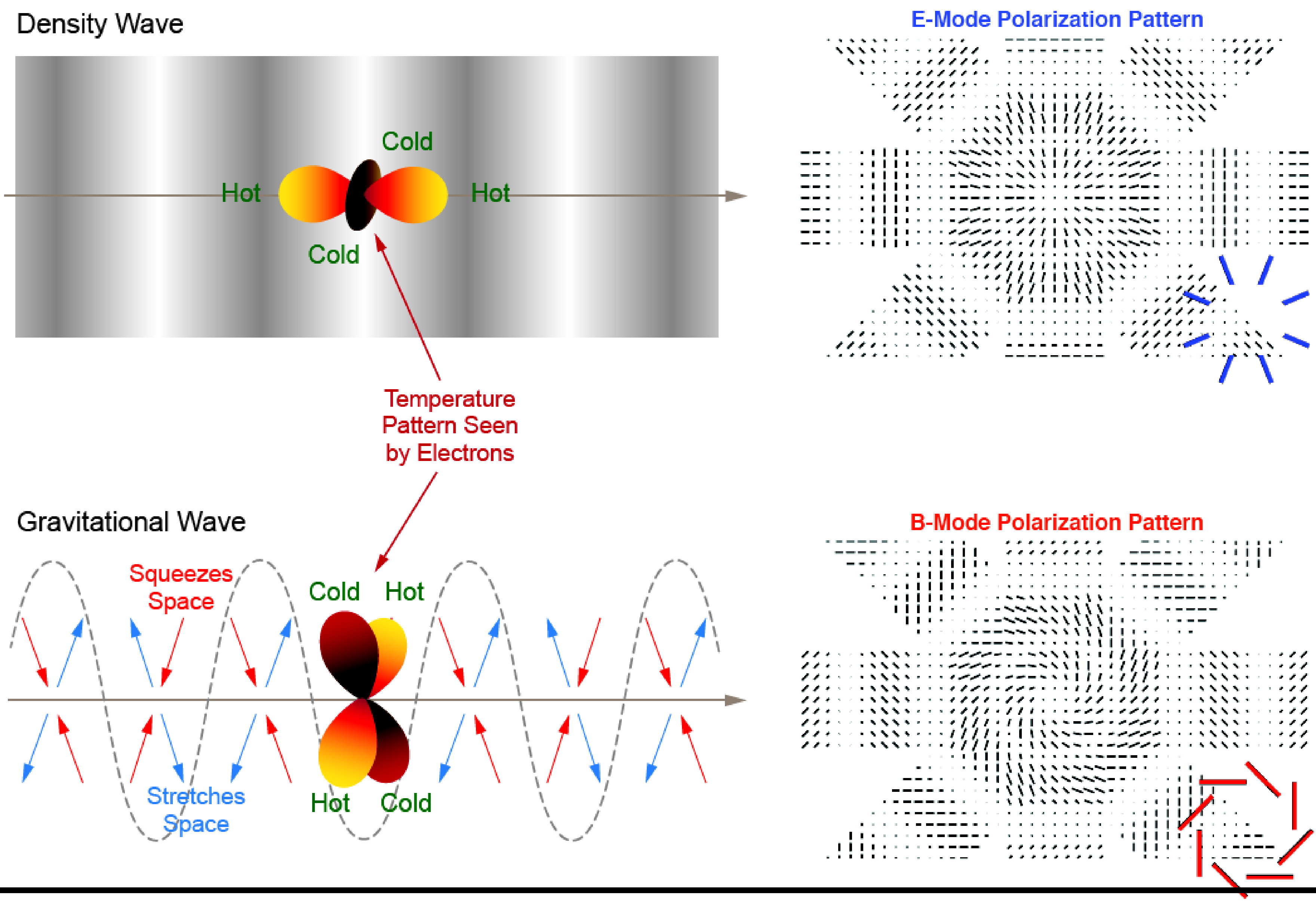
- Component "E-mode" or "gradient mode", no deviation
- Component "B-mode" or "rotor mode", with deviation

Mode E may be due to both scalar and tensor disturbances, but mode B is solely due to tensor perturbations.





E-mode pure B-mode pure

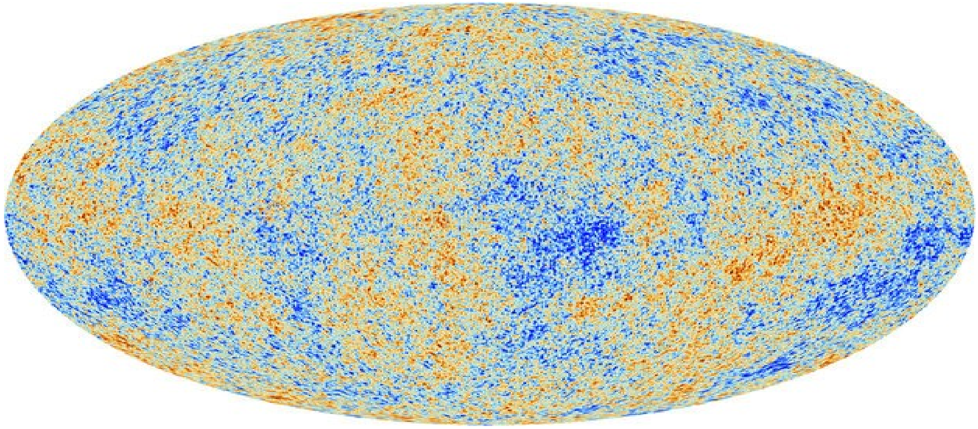


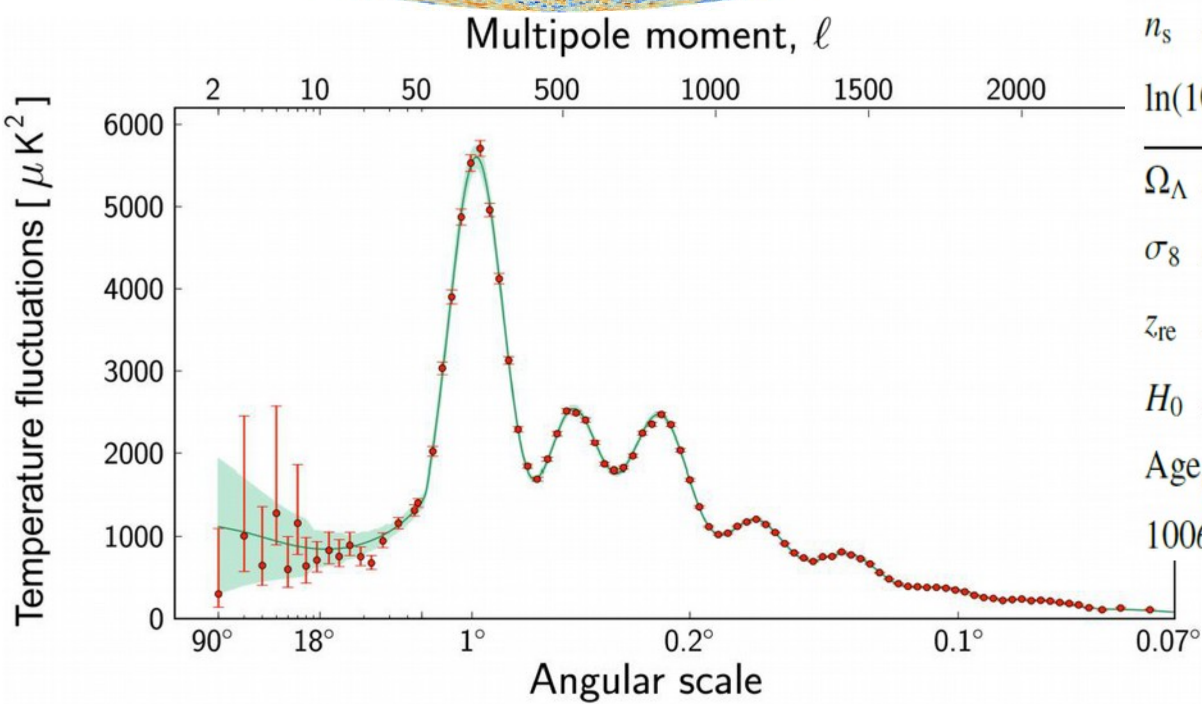
Fluctuations in densty doest not generate B-mode

But the **"lenssing effect" can transforms E-mode into B-mode**
(Zaldarriaga, Seljak 1998)

Determination of cosmological parameters

2013 (Planck)



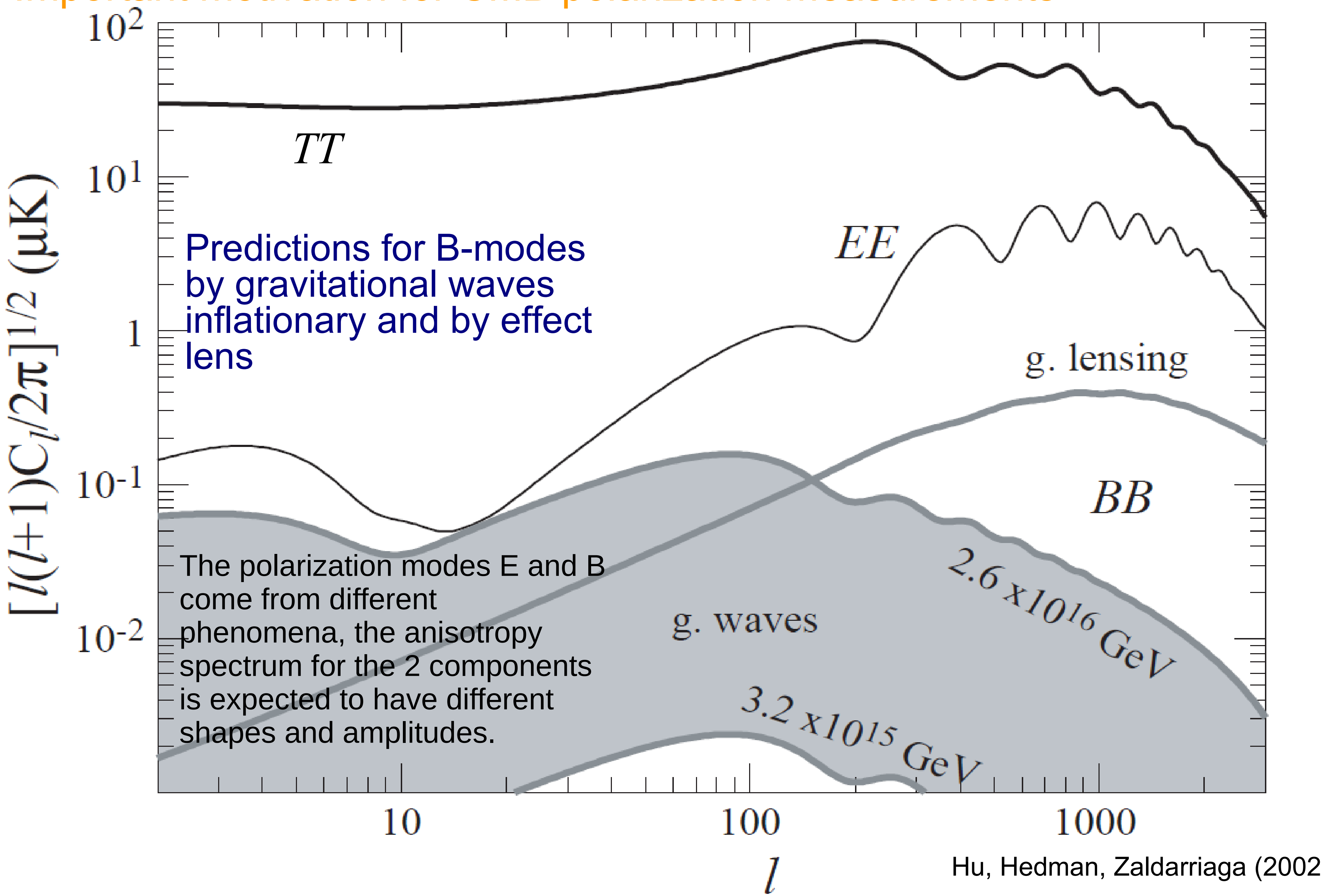


	Planck (CMB+lensing)	
Parameter	Best fit	68 % limits
$\Omega_b h^2$	0.022242	0.02217 ± 0.00033
$\Omega_c h^2$	0.11805	0.1186 ± 0.0031
$100\theta_{MC}$	1.04150	1.04141 ± 0.00067
τ	0.0949	0.089 ± 0.032
n_s	0.9675	0.9635 ± 0.0094
$\ln(10^{10} A_s)$	3.098	3.085 ± 0.057
Ω_Λ	0.6964	0.693 ± 0.019
σ_8	0.8285	0.823 ± 0.018
z_{re}	11.45	$10.8^{+3.1}_{-2.5}$
H_0	68.14	67.9 ± 1.5
Age/Gyr	13.784	13.796 ± 0.058
$100\theta_*$	1.04164	1.04156 ± 0.00066

The simplest inflationary model predicts a relative intensity between scalar-tensor fluctuations r> 0.01.QUBIC aims to study the values of this parameter between 0.01 and 0.1

Ratio Tensor/Scalar: r < 0.11 (95% CL)

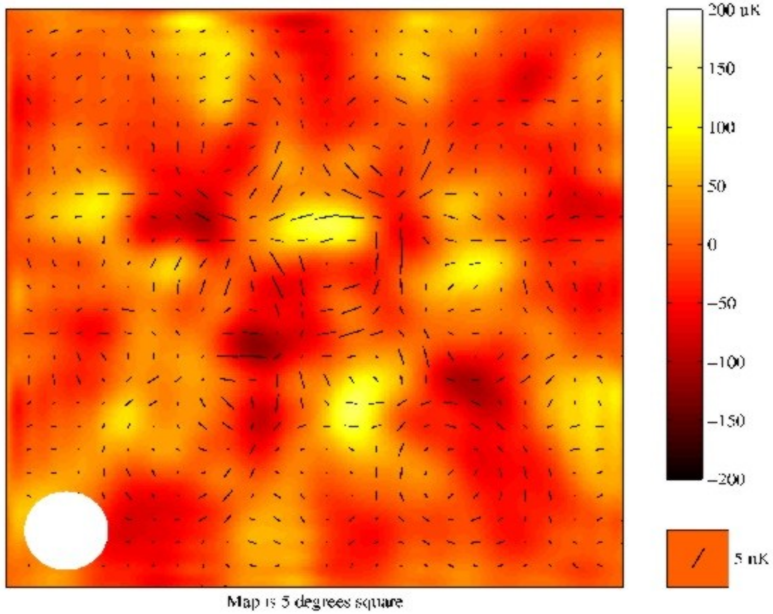
Important motivation for CMB polarization measurements

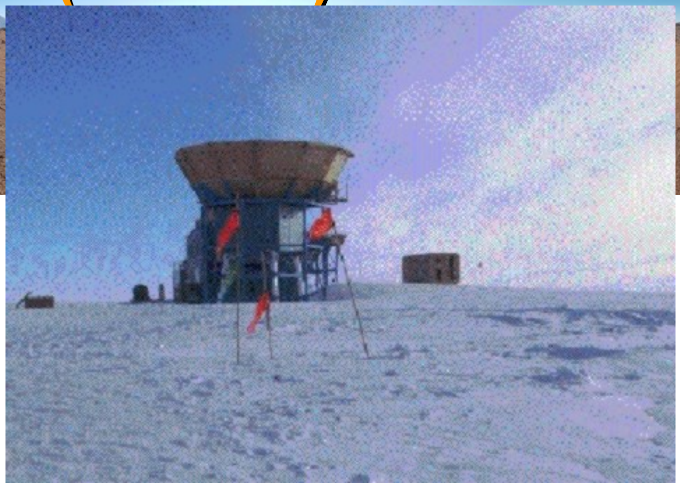


Hu, Hedman, Zaldarriaga (2002)

Planck data → the energy scale during inflation must have been < $3\text{x}10^{16}$ GeV (Kaplinghat 2003).When the signal of the gavitational waves is detected, we will be able to find the energy scale of the event that occurred 10^{-35} seconds after the origin of the Universe.

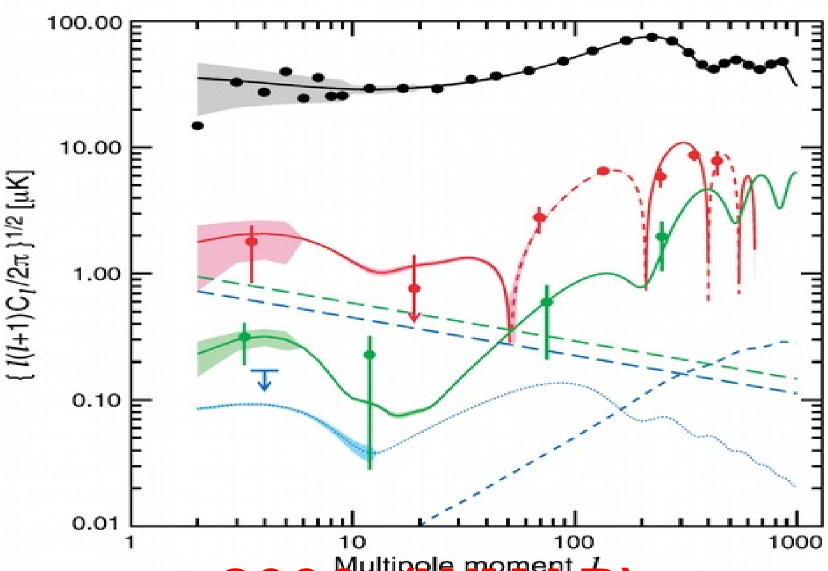
2002: 1st polarization detection (E-mode)



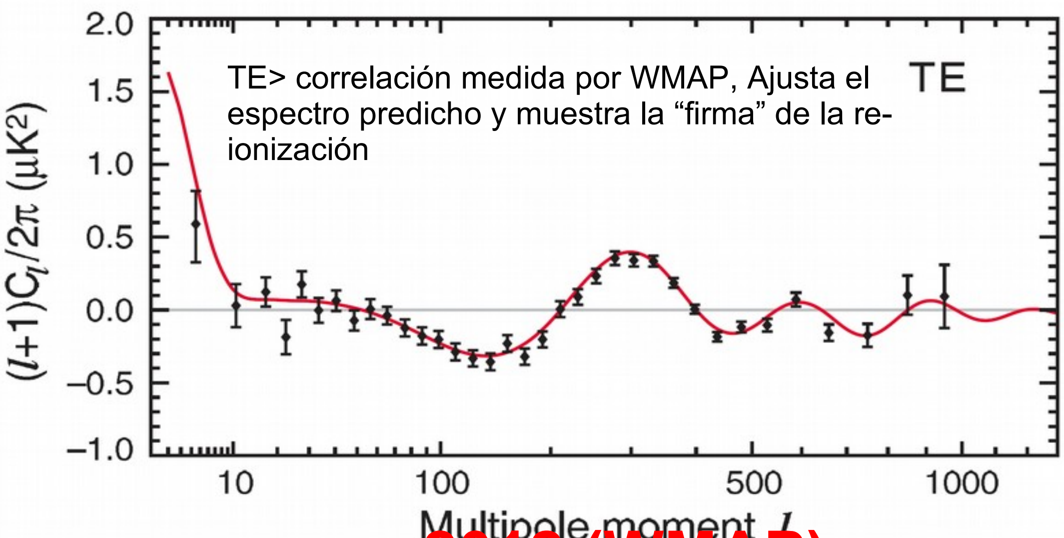


Degree **A**ngular **S**cale **I**nterferometer

T = 2.73 K ΔT= 50 μK ΔT_{pol} = 5 μK

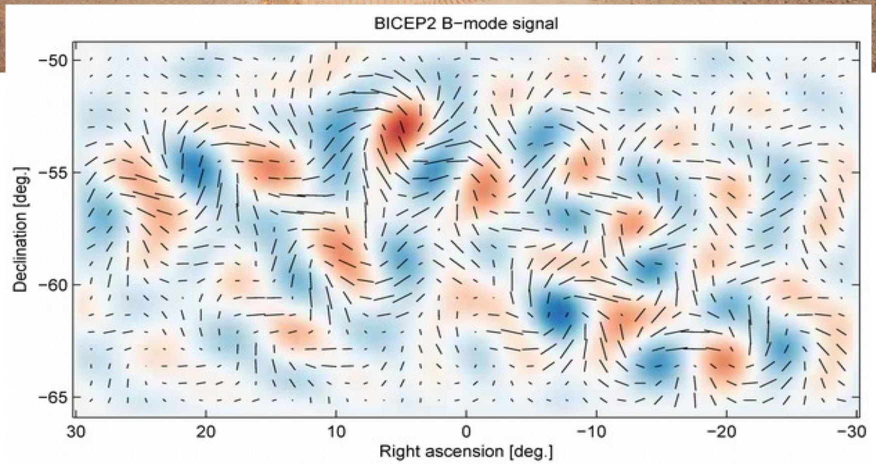


2006 (WMAP)



2012 (WMAP)

March, 2014: Anouncement (premature) of B-mode detection

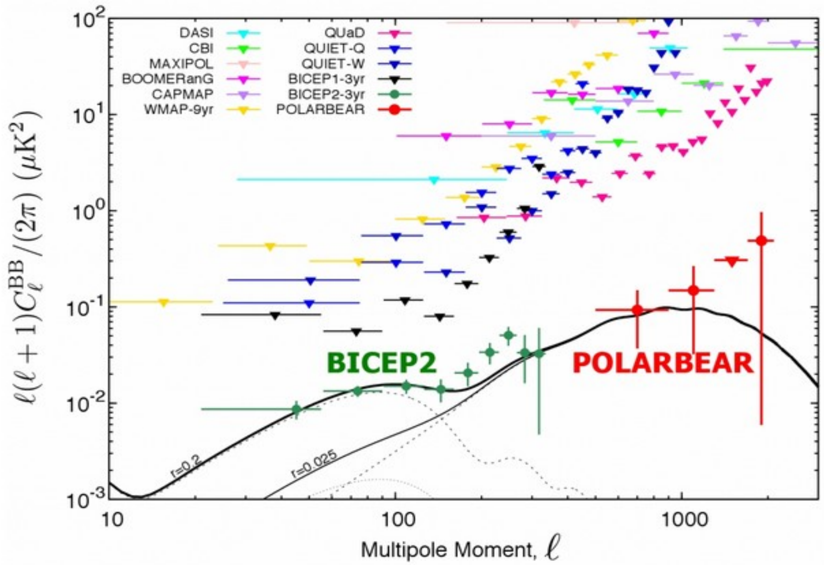


International impact….

BICEP-Planck-Keck Array joint subsequent analysis (more frequencies): Signal dominated by polarized emission of galactic dust

SPT and POLARBEAR

They measured (shortly before BICEP2) Supported B modes with what is expected by transformation mode E by lens effect (at smaller angular scales)



The search for primordial B-modes continues …

Ongoing experiments:

BICEP3/Keck Array, SPT, EBEX, Spider (USA,Antártida), CLASS,

Project	Frequencies (GHz)	ℓ Range	Ref.	$\sigma(r)$ goal	
				no fg.	with fg.
QUBIC	150,220	30–200		6.0×10^{-3}	1.0×10^{-2}
Bicep3/Keck	95, 150, 220	50–250	[8]	2.5×10^{-3}	1.3×10^{-2}
CLASS	38, 93, 148, 217	2–100	[9]	1.4×10^{-3}	3.0×10^{-3}
SPT-3G	95, 148, 223	50–3000	[10]	1.7×10^{-3}	5.0×10^{-3}
AdvACT	90, 150, 230	60–3000	[11]	1.3×10^{-3}	4.0×10^{-3}
Simons Array	90, 150, 220	30–3000	[12]	1.6×10^{-3}	5.0×10^{-3}
EBEX-10K	150, 220, 280, 350	20–2000	[13]	2.7×10^{-3}	7.0×10^{-3}
SPIDER	90, 150	20–500	[14]	3.1×10^{-3}	1.2×10^{-3}
PIPER	200, 270, 350, 600	2–300	[15]	3.8×10^{-3}	8.0×10^{-3}

Why is it so difficult to measure B-modes?

Sensibility

Signal amplitude ~ 70 nK over 3K background

Need for extremely sensitive and stable detectors at ~ 150 GHz

Astrophysic foreground :

BICEP2 false alert: showed its importance Thermal emission of interstellar dust Need for high frequency detectors at > 150 GHz Synchrotron emission may be important

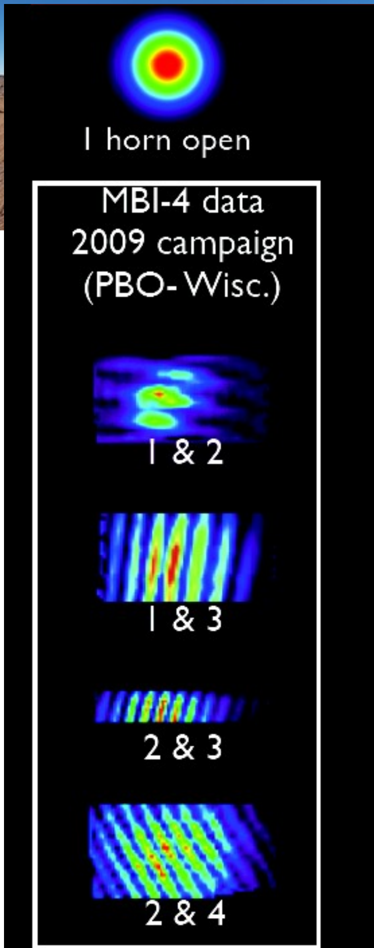
Sistematic Effects

Need for precise polarization modulation and detailed knowledge of instrumental properties

Atmosphere

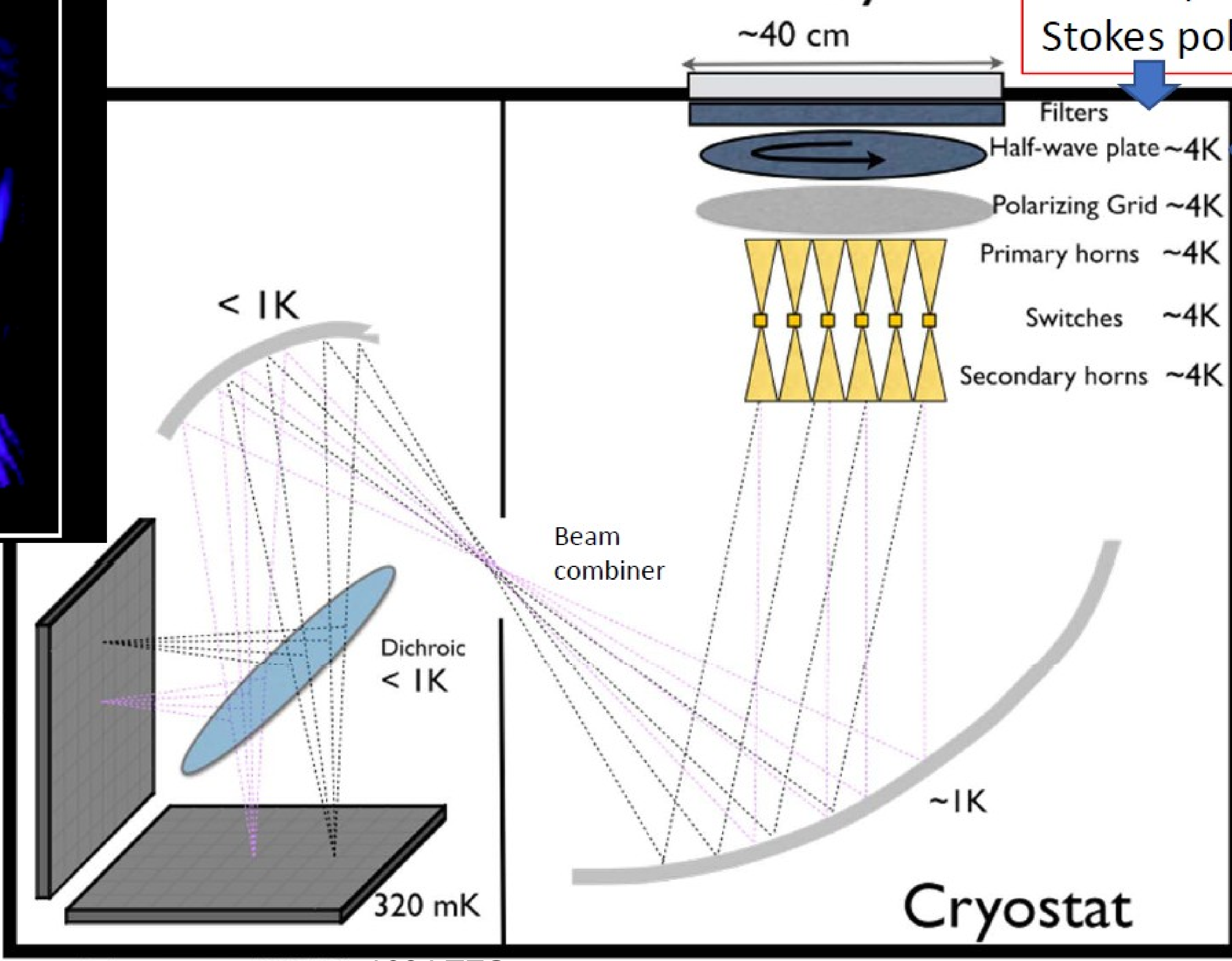
QUBIC – Design

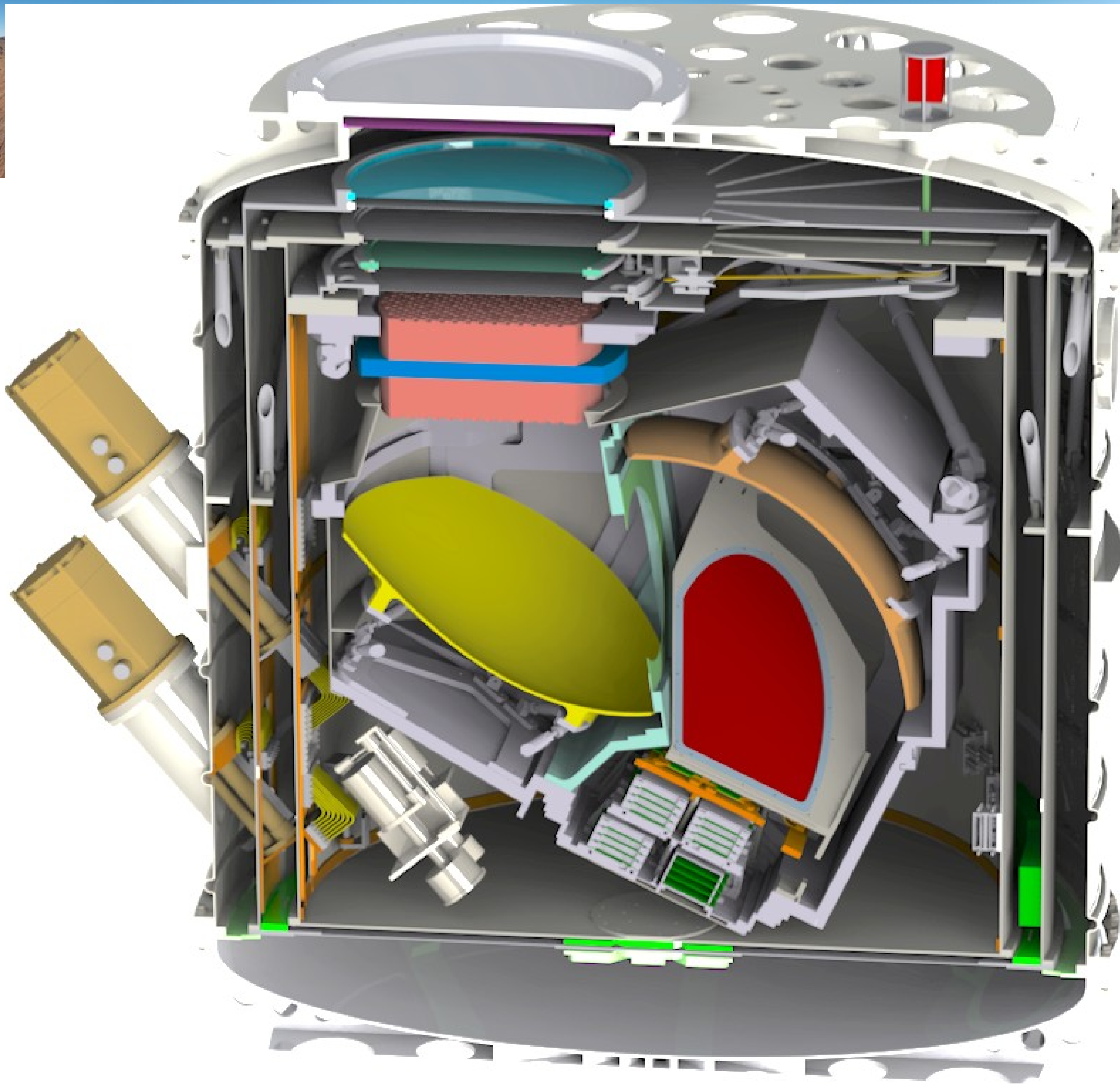
instrument that combines the extreme sensitivity of a bolometric array with the control of the interferometer signal



HWP + polarizer =
Stokes polarimeter

polarization modulation before optical system





Complete Design

External Criostate: Roma
1K Box / detectors: APC
Coolers: Manchester
Optics: Roma / Maynooth

1.6m high
1.4m diameter
800Kg weight

Main Characteristics

Bolometric interferometer of 400 elements
-Sythetic image in the focal planes
Resolution -23.5 arcmin FWHM at 140 GHz

Synthesized imager, scans the sky under good beam control

- **Focal planes:TES**

- 2048 TES with NEP ~ $4x10^{-17}$ W.$Hz^{-1/2}$
- 128:1 SQUIDs+ASICcryogenic multiplexed reading system (4K)

High sensitivity (r) = 0.01 including foregrounds

- **Frequency capabilities**

-2 focal planes 150 & 220 GHz
- Spectro-Imaging capabilities thanks 2 frequencies at the syntetized beam

Polarization pollution from dust removal

- **Indvidual Aperture stwitches (horn)**

-Individual reconstruction of the baseline
-Self-Calibration like an interferometer

Unprecedented instrumental system control with self-calibration

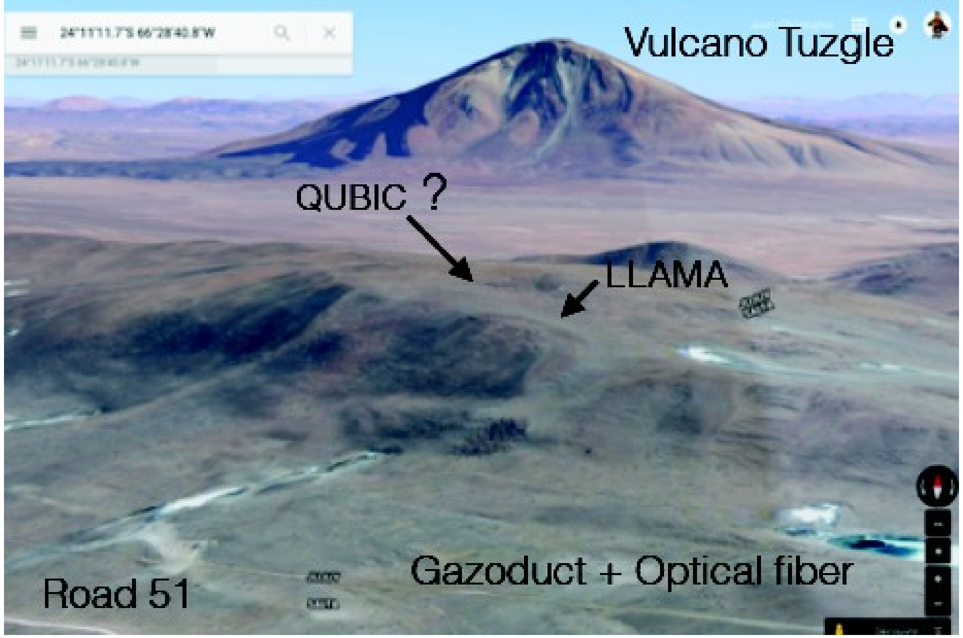
QUBIC site

Initial location: Concordia
(France-Italy station), Antártida

Adventages: ideal atmosphere
Disadventages: logistics, costs.

Alternative site: Alto Chorrillo-Salta

Adventages
accesibility
logistics (LLAMA)
Argentinean participation
Disadventages: reduced sensibility
in a factor 1-3



QUBIC-Site


Ruta Provincial 74
QUBIC (24°11'11.71"S; 66°28'40.79"W)
Possible site for QUBIC
~ 500 m
Antena Holografica
Sitio "D" LLAMA
Vega Falda Cienega
Ruta Nac 51
Camino Acceso LLAMA
Laguna Escondida
Linea de alta Tension
Gasoducto
Alto de Chorrillos
Volcán Tuzgle (5500m asl)
QUBIC ?
LLAMA
Ruta 51
Gasoducto + fibra óptica
San Antonio de los Cobres
40
51
S / Astrium
Google earth

QUBIC-Site

★ Puna Argentina - Salta
 5000m a.s.l.
★ ~ 180km from Chajnantor (Atacama)

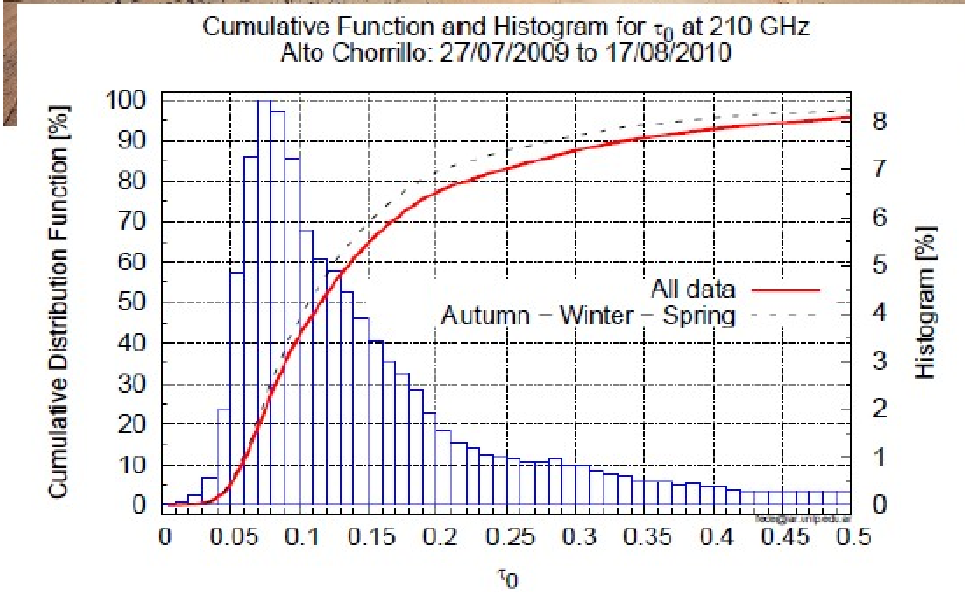
- Logistics and sinergy with LLAMA

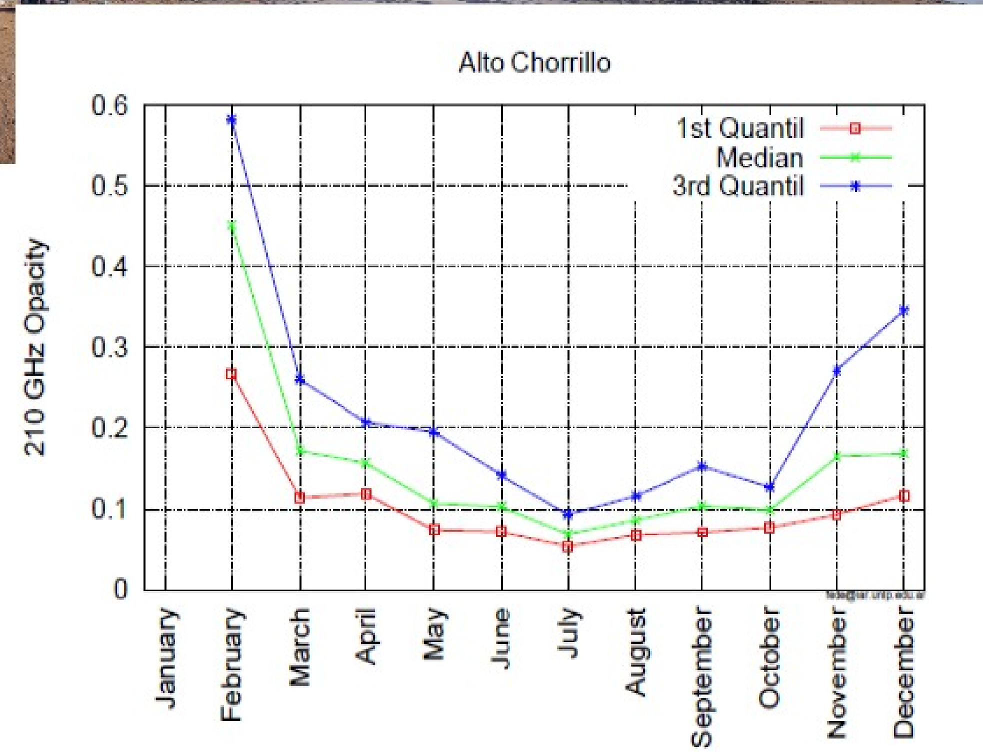
★ 40 min. from San Antonio de los Cobres by auto.
★ 4h from Saltacity
★ Logistics (roads, water, dorms at the mountain): argentiniana collaboration

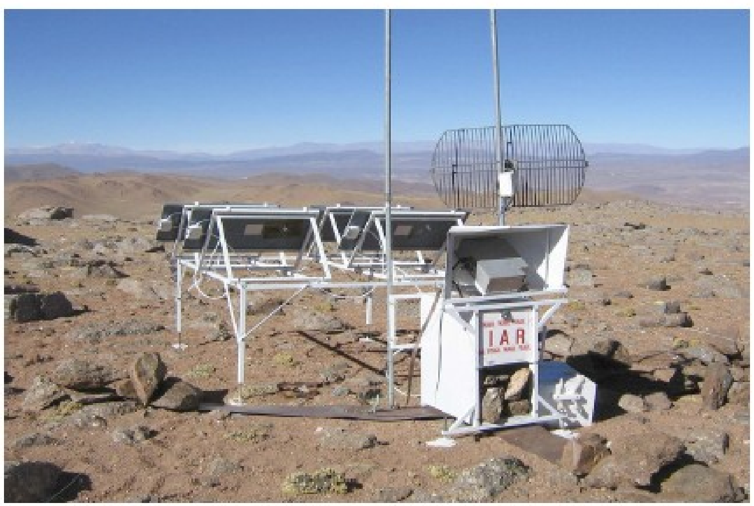
- Argentinian Collabration

★ MINCYT
★ CONICET / CNEA / Provincia de Salta

Opacidad atmosférica a 210 GHz







Mediciones con "tipper" provisto por UNAM
Julio 2009 – Agosto 2010

La mediana (2nd quantil) presenta un buen $\tau<0.20$ para todos los meses, excepto para Febrero (parte del verano boliviano)

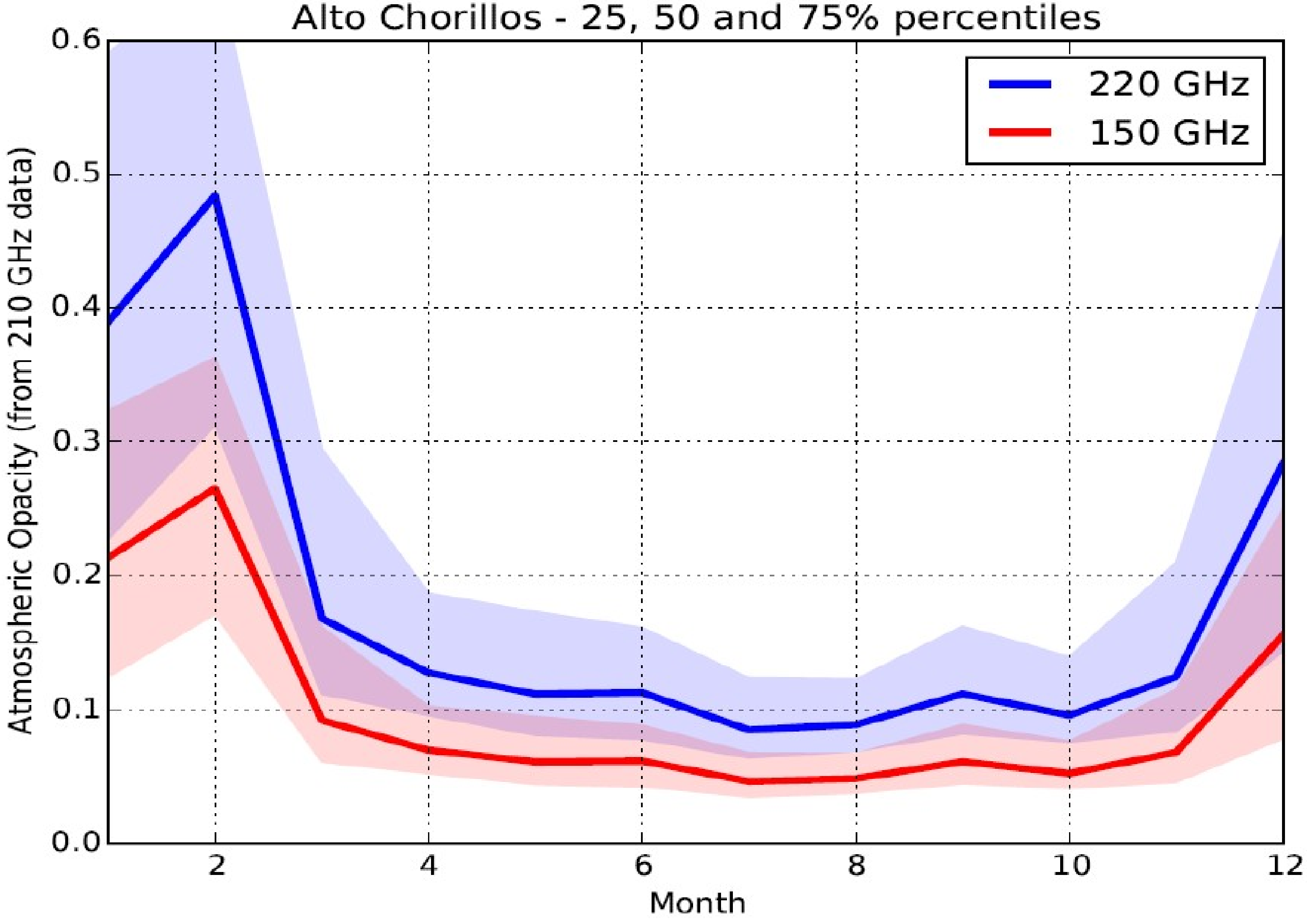
$\tau < 0.20$

Cuantil	$^{*}\tau_{225} \leq$ Chajnan. 5060 m	M. Kea 4100 m	Polo Sur 2835 m	$\tau_{210} \leq$ Jarillal# 3160 m	Macón@ 4604 m	Chorrillo 4813 m
25 %	0.04	0.06	0.04	0.17	0.082	0.074
50 %	0.06	0.09	0.05	0.22	0.114	0.107
75 %	0.12	0.15	0.07	0.29	0.169	0.167

*: *Radford (2000)*, #: Bareilles et al. (2003), @: *Bareilles et al. (2005, 2007)*

Bareilles et al, BAAA Vol. 53, 2010

Opacidad atmosférica a 150 y 220 GHz

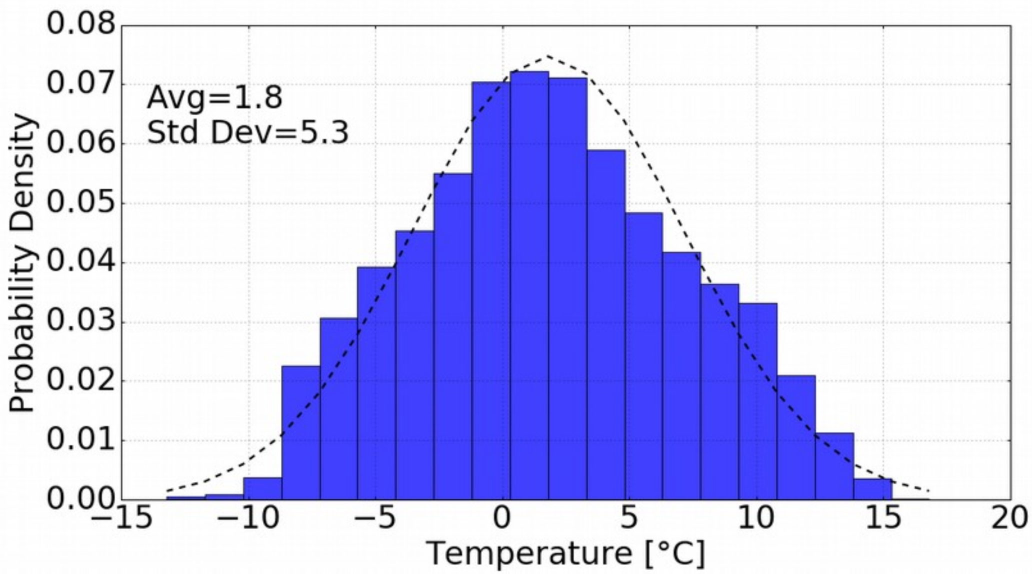


EXTRAPOLACION

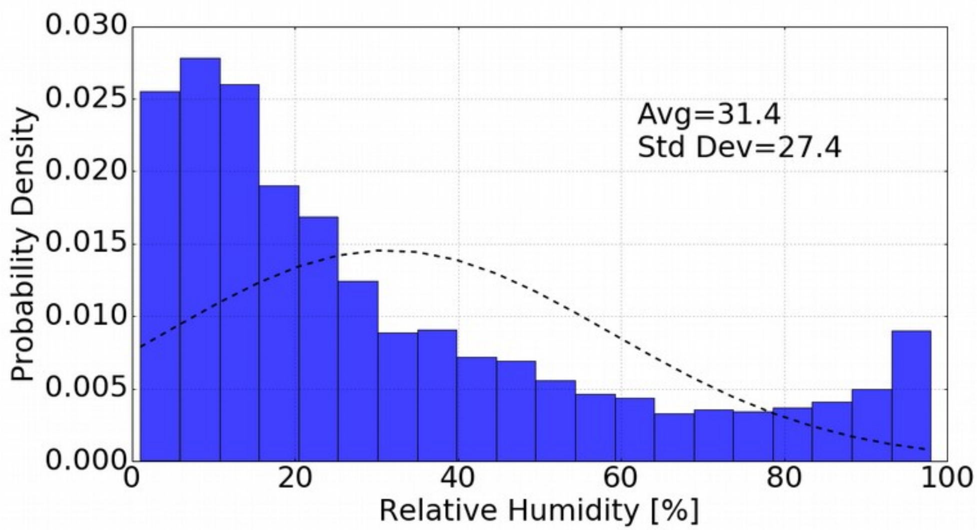
valores esperados para las fecuencias de QUBIC,

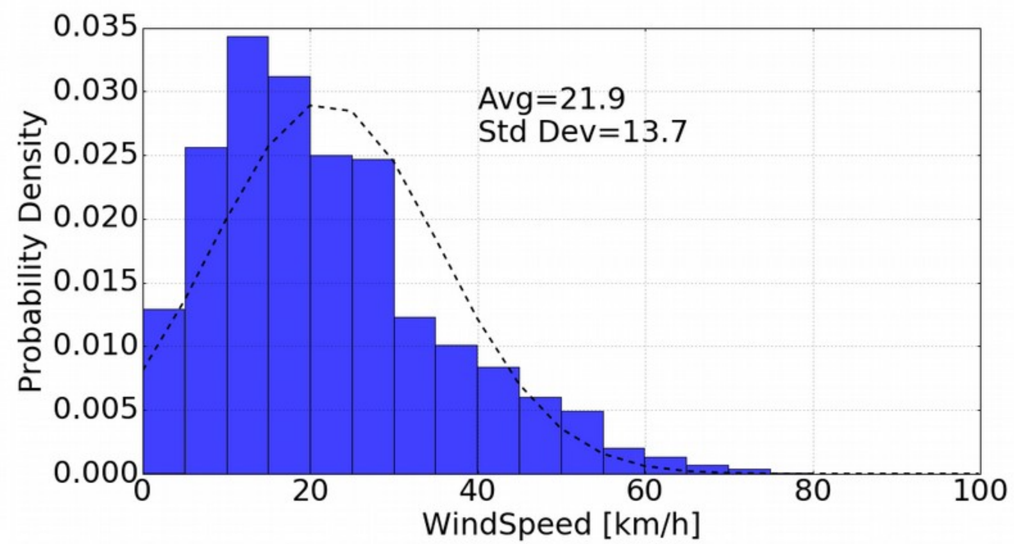
- 150 GHz y 220 GHz, usando el modelo atmosférico de Chajnantor.

Meteorological Data



Within the specifications of international collaboration





QUBIC in Argentina
ANTECEDENTS and CHRONOLOGY

- Previous collaborations: Pierre Auger Obsevatory.
- Cooperation CAB – APC detection detectors (TES, MKIDs)
- QUBIC: Concordia, Antártida
- Logistic difficulties, cost involved: search for alternative sites

22/09/2015: visit to Alto Chorrillo

Jean-Christophe Hamilton (PI QUBIC)
Sotiris Loucatos (Director adjunto del APC)
Etienne Saur (France Embassy)
Beatriz García (ITeDA), José Viramonte (LLAMA)

Oct.13th, 2015: presentation of the project to MINCyT

QUBIC Meeting, July,9th 2016, Roma

Presentation and acceptance of the Argentine site and the incorporation of Argentina in the collaboration

QUBIC

a Q&U Bolometric Interferometer for Cosmology

More than
100 members

6 counties
22 labs

APC Paris, France
CSNSM Orsay, France
IAS Orsay, France
IEF Orsay, France
IRAP Toulouse, France
LAL Orsay, France
Universita di Milano-Bicocca, Italy
Universita degli studi di Milano, Italy
Universita La Sapienza, Roma, Italy
Maynooth University, Ireland
Cardiff University, UK
University of Manchester, UK
Brown University, USA
Richmond University, USA
University of Wisconsin, USA
Centro Atómico Constituyentes, Argentina
GEMA, Argentina
Comision Nacional de Energia Atomica, Argentina
Facultad de Cs Astronómicas y Geofísicas, Argentina
Centro Atómico Bariloche and Instituto Balseiro, Argentina
Instituto de Tecnologías en Detección y Astropartículas, Argentina
Instituto Argentino de Radioastronomía, Argentina

43 Argentinean members:
researchers, engineers,
technicians, students (2018)

PI J.C. Hamilton, APC Paris

Institutional Support

CONVENIO CUATRIPARTITO PARA EL PROYECTO DEL OBSERVATORIO INTERNACIONAL QUBIC

Argentina, a los 22 días del mes de Diciembre de 2017

Dr. J.M. URTUBEY
Gobernador de la Provincia de Salta

Dr. J.L.S BARAÑAO
Ministro de Ciencia, Tecnología e Innovación Productiva

Dr. H.A. CECCATTO
Presidente del Consejo Nacional de Investigaciones Científicas y Técnicas

Lic. O. CALZETTA LARRIEU
Presidente de la Comisión Nacional de Energía Atómica

CONVENIO CUATRIPARTITO PARA LA EJECUCIÓN DEL PROGRAMA INTERINSTITUCIONAL DE DESARROLLO DEL PROYECTO LABORATORIO INTERNACIONAL ANDES

República Argentina, a los 12 días del mes de ABRIL de 2018.

Dr. S. M. UÑAC
Gobierno de la Provincia de San Juan

Dr. J. L. S. BARAÑAO
Ministerio de Ciencia, Tecnología e Innovación Productiva

Lic. O. CALZETTA LARRIEU
Comisión Nacional de Energía Atómica

Dr. H. A. CECCATTO
Consejo Nacional de Investigaciones Científicas y Técnicas

Highest Institutional Support: Govs. San Juan, Salta, Fed. Minister S&T, Pres. CNEA, CONICET

Dear Lic. Calzetta

I am very pleased to confirm the great interest of our company, MCC Minera Sierra Grande, in supporting the scientific and technological developments that are taking place in your institution, the Comisión Nacional de Energía Atómica. To that end, we propose to facilitate access to a site located at level 480 of our mine for the operation of physics research experiments. This site has approximately 400 m of rock coverage and it will be provided as long as this does not affect the regular operation of our company. In particular, we would need to sign a specific agreement as soon as possible detailing the responsibilities of each Party, before proceeding with the installation of a group of detectors by the end of the year.

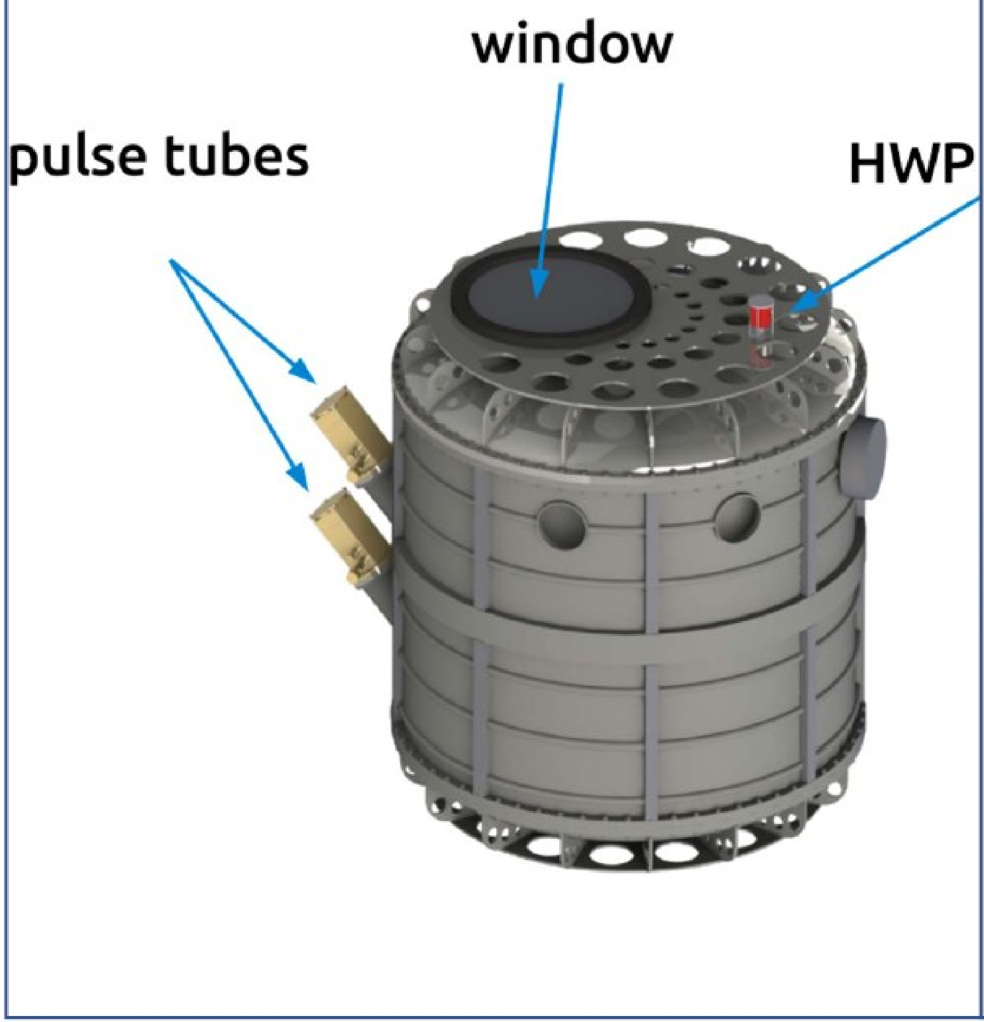
Yours sincerely

Ing. CHEN QIFANG
Presidente y Apoderado
Esc. 970 - F° 1254
Reg. 36 (R.N.) 30/10/2015
MCC Minera Sierra Grande S.A

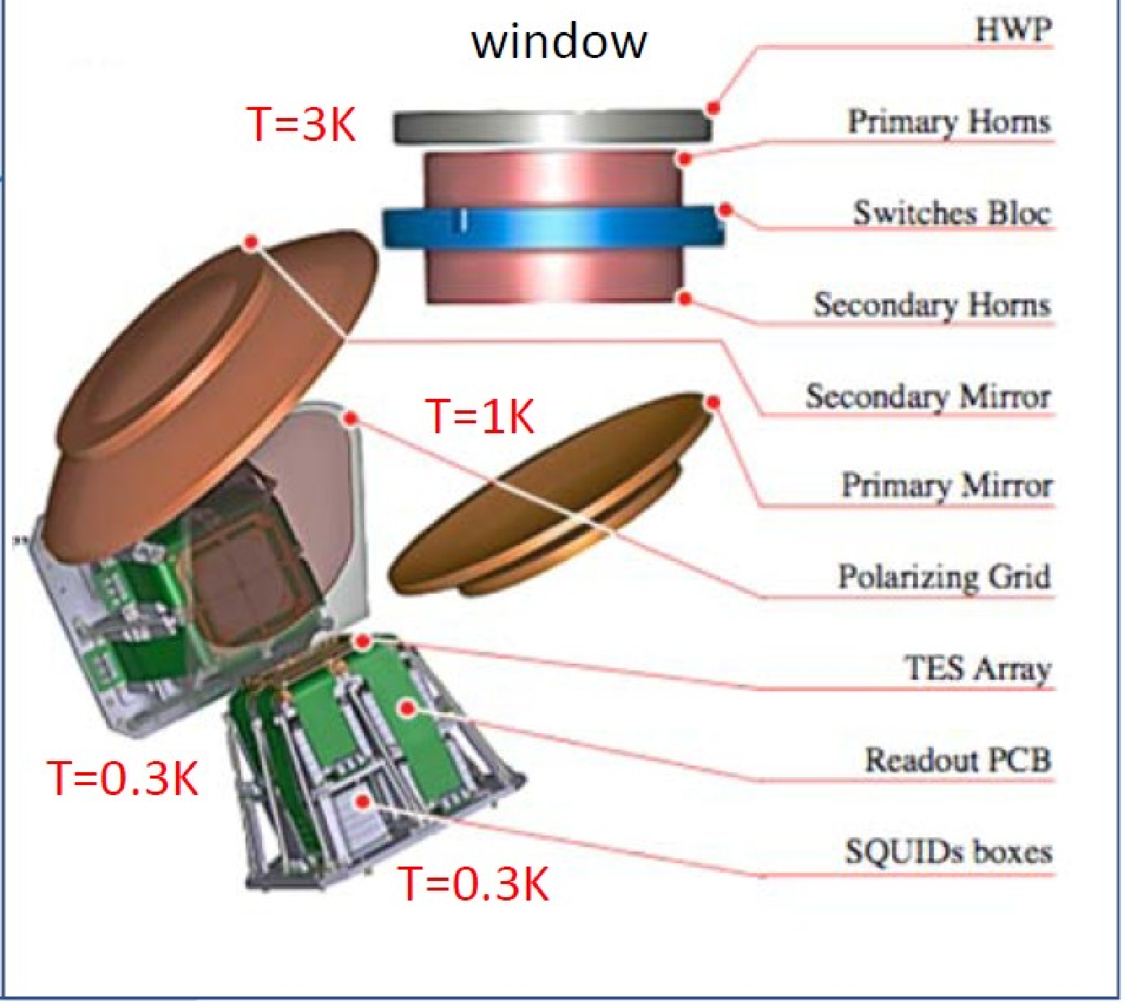
Chile requested to join HILCQUAD efforts
Eager and ready to start with HILCQUAD!

Instrumental Implementation

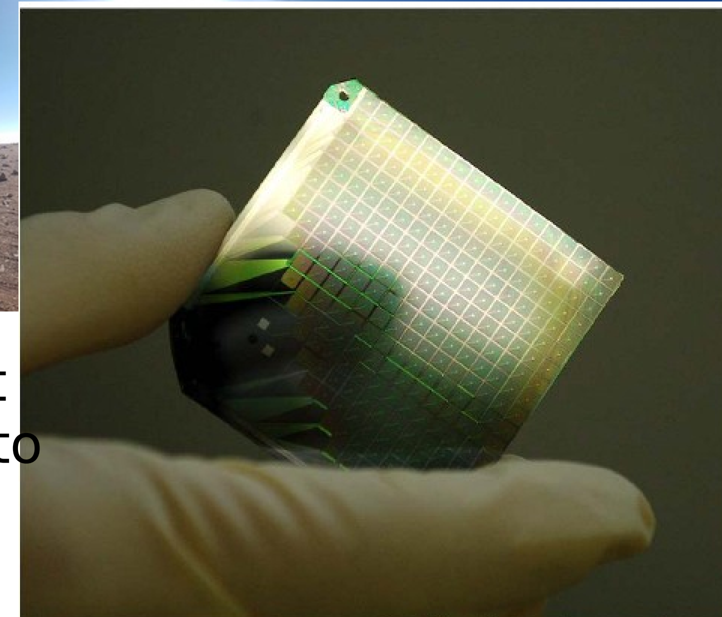
Exterior



Interior

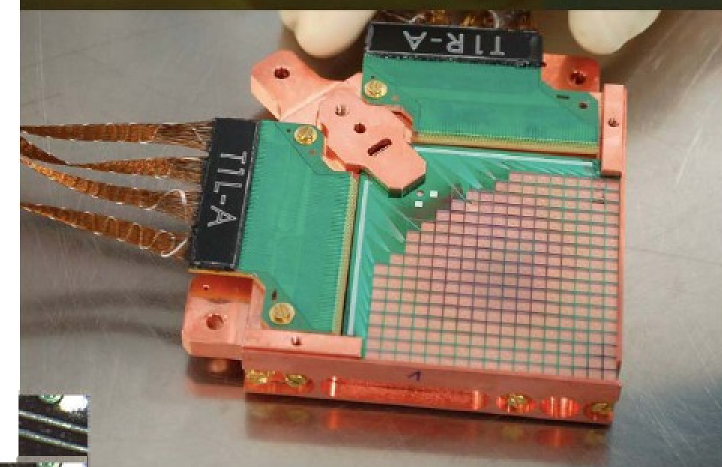


TES array



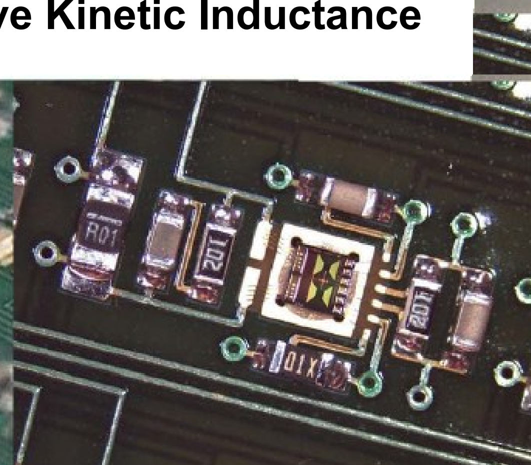
Transition Edge Sensors (TES): Bolometers that use the normal transition of a superconductor to detect extremely small temperature variations (320mK).

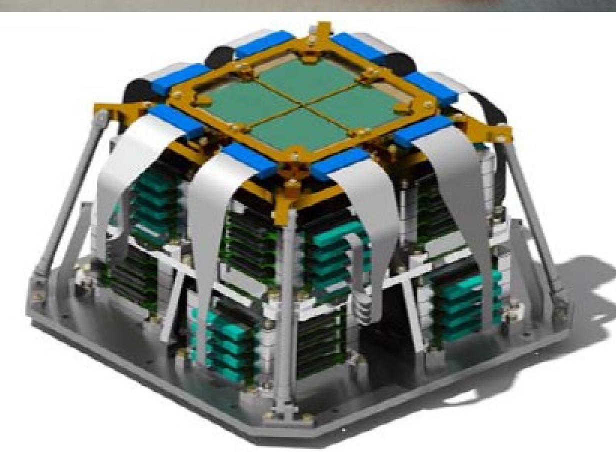
- film Nb_xSi_{1-x}
- Good performance (>80%)
- Uniformity through wafer (<10%)
- Coplex built process



Made in CSNSM Orsay

Evolution to MKIDs (Microwave Kinetic Inductance Detector)





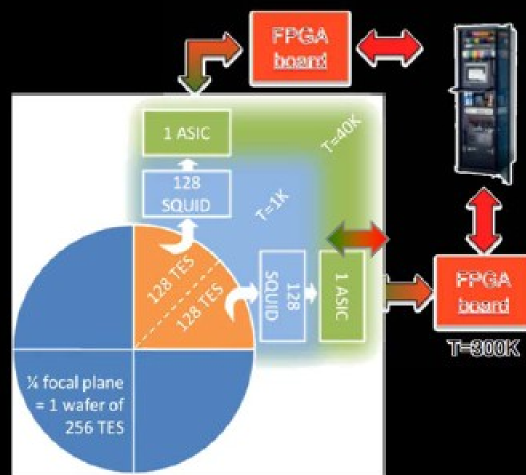
Perbost, C., Marnieros, S., Bélier, B. et al. J Low Temp Phys (2016) 184: 793

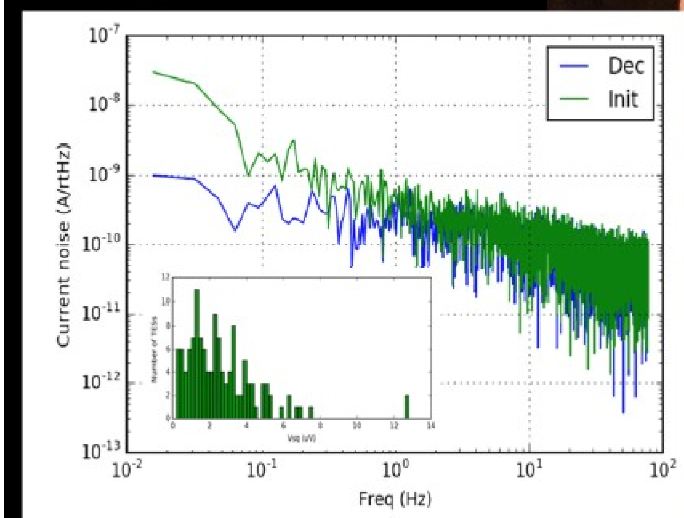
Chain detection

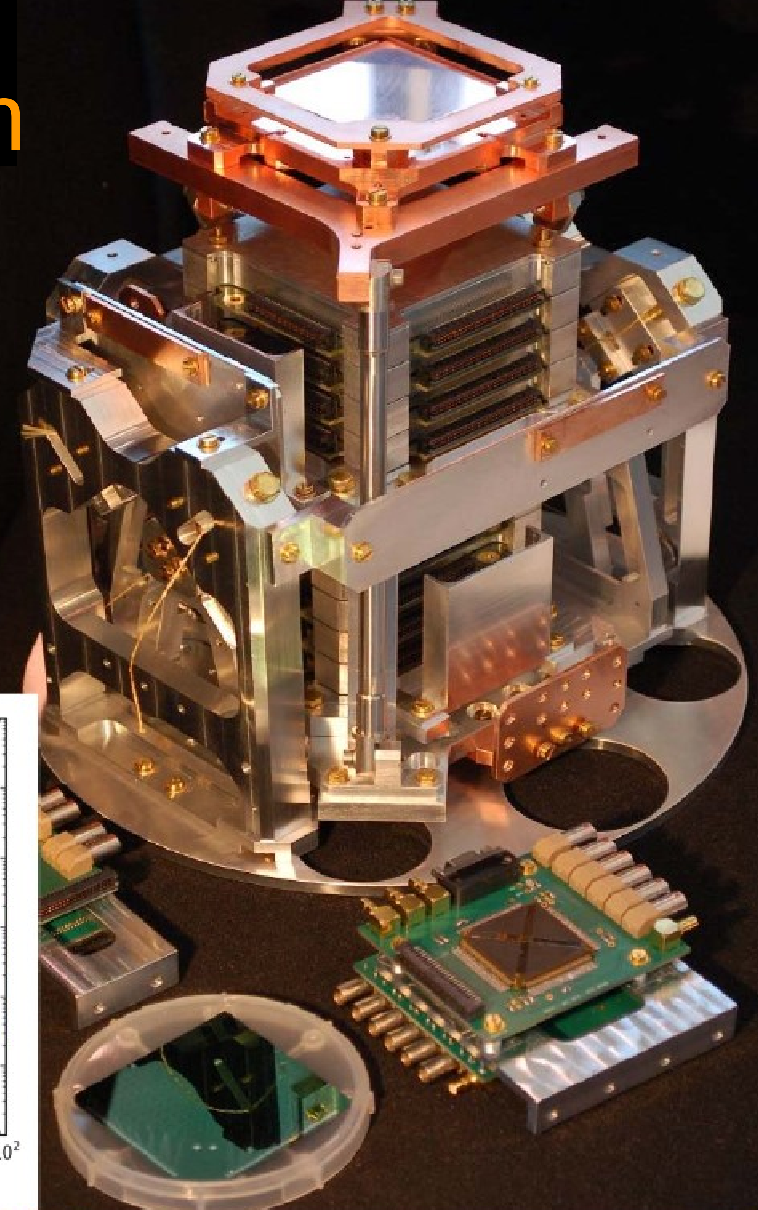
Made in APC-Paris
(M. Piat, APC)

- 1 focal plane = 4 wafers of 256 TESs @300mK
- Lectura: Time Domain Multiplexing 128:1
- 128 SQUIDs @ 1K + 1 ASIC @ 40 K para ⅛ plano focal
- Especifications:
  - NEP < 5.10^{-17} W.Hz$^{-0.5}$
  - τ < 10ms
- ASICs cooled

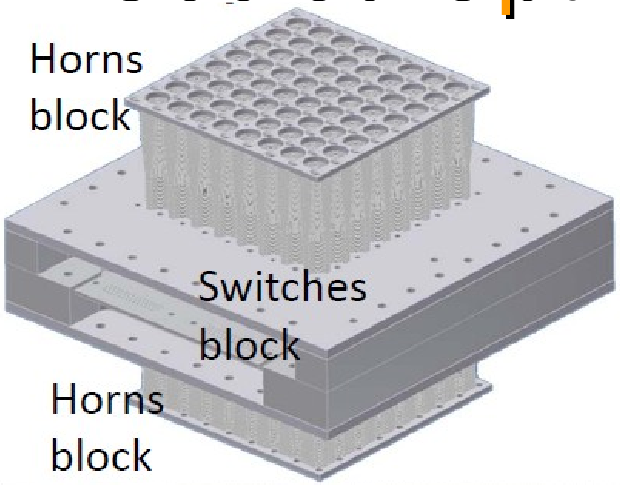
- FI: 2 focal planes: 150GHz and 220GHz
- TD: 1 focal plane with 256 TESs (150GHz)
- Data acquistion & control SW made in IRAP-Tolouse

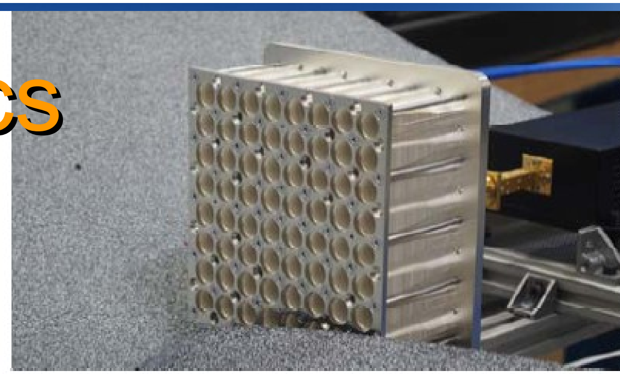


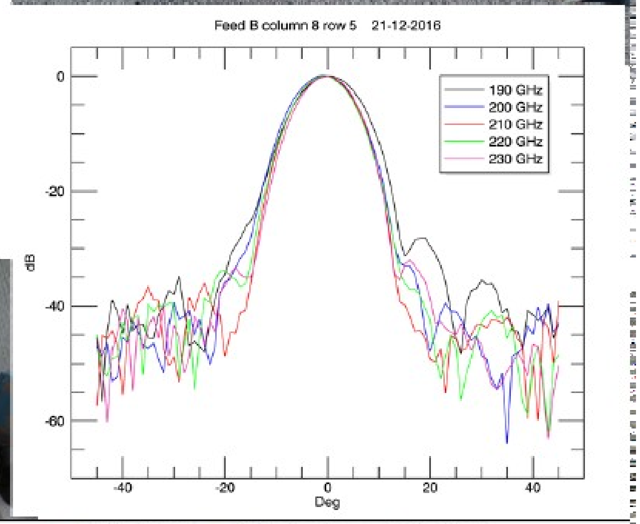


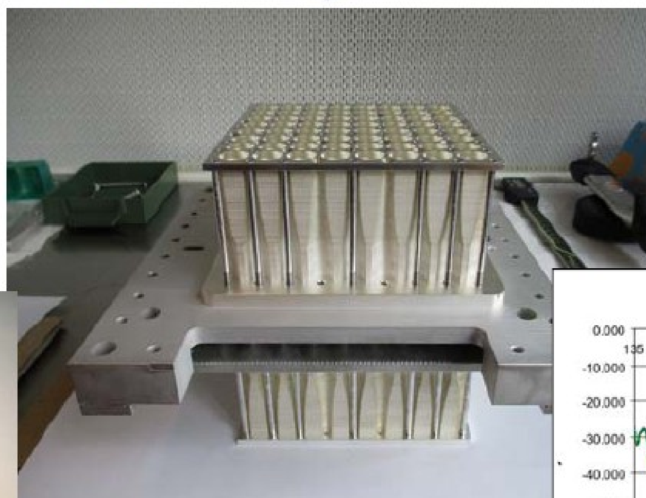


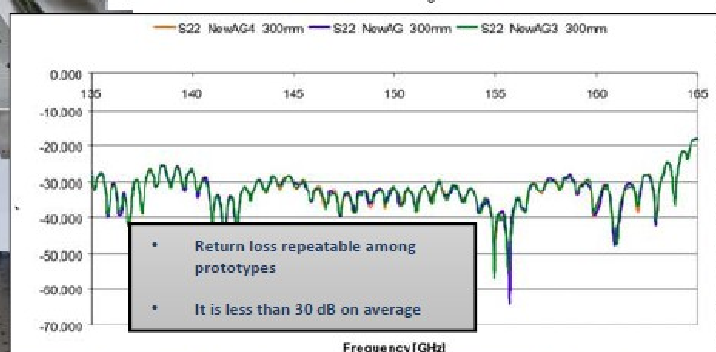
Cooled Optics

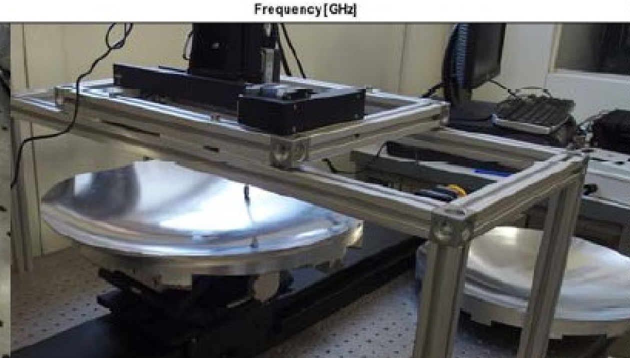






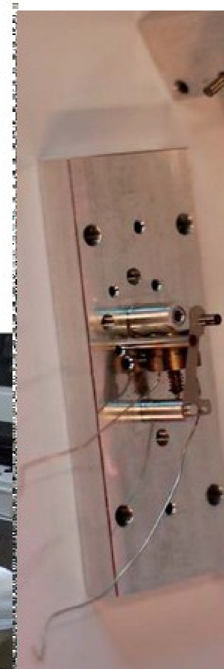






- Platelets - Corrugated feedhorns arrangement made inMilan, tested in Bicocca, Arrays of 140GHz and 220GHz

- Excellent performance.
- Switches array



Sub-K Coolers

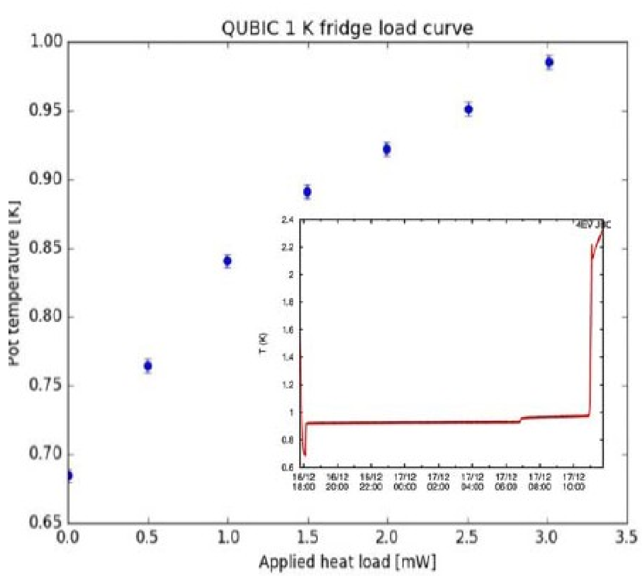
Made in Manchester

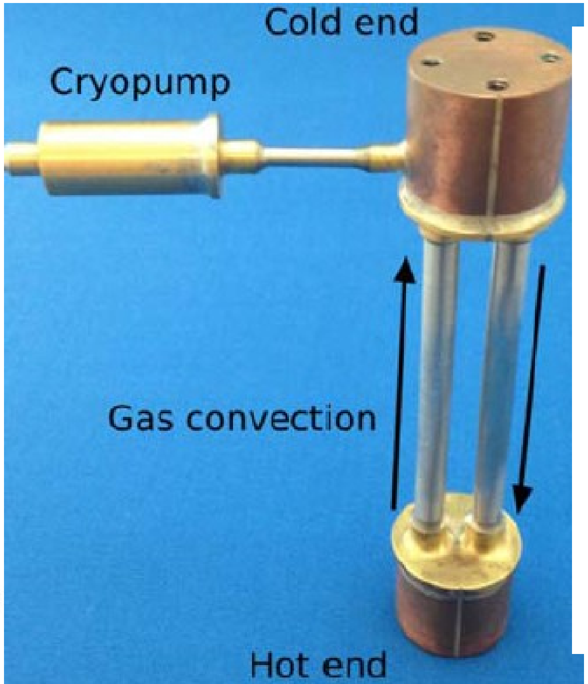
Challenges:

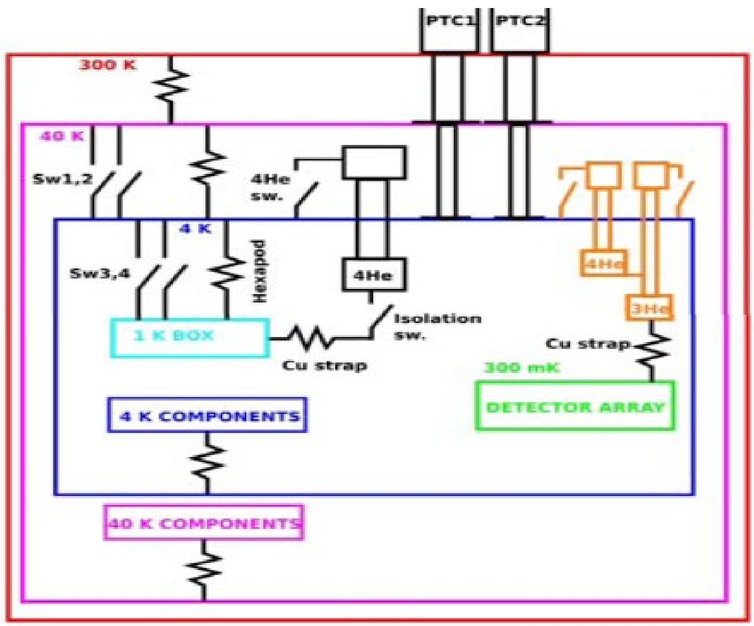
- Cool 160 kg of metal to < 1K
- Cool the focal plane to 0.3K
- High evaporation of refrigerators a

heat switches, gas:

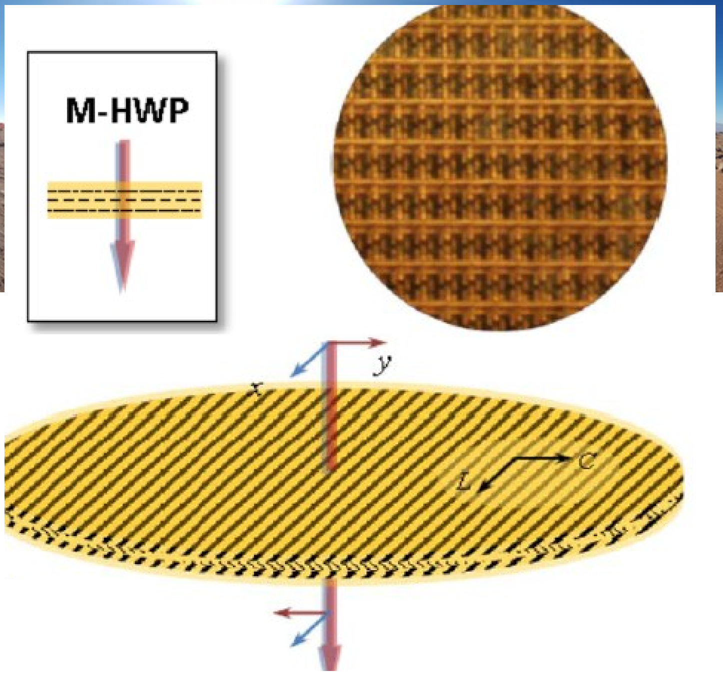
- ^{3}He for the focal plane
- ^{4}He for the 1K box







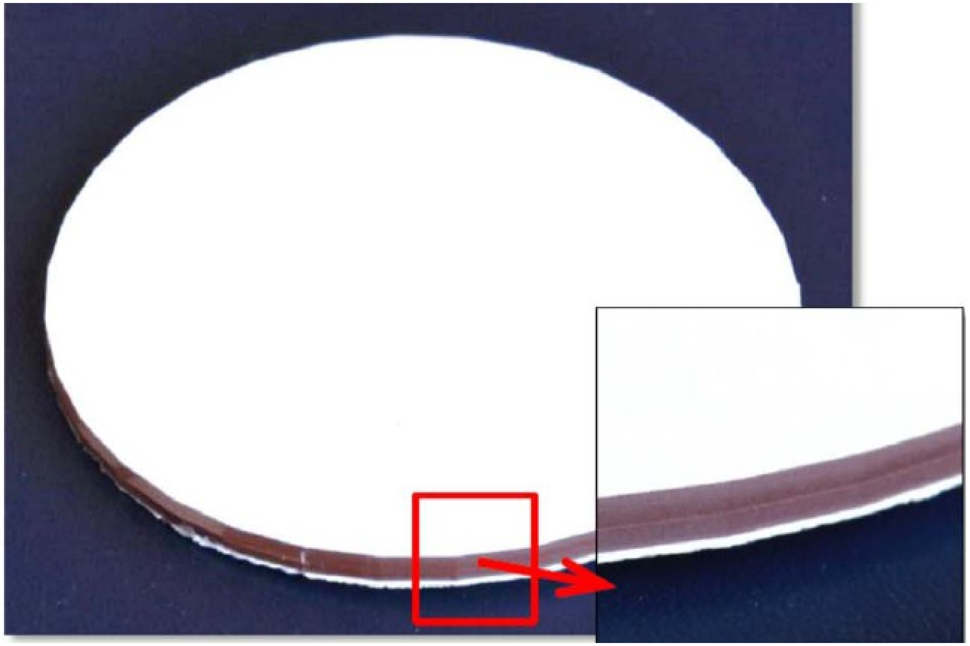
Optical filters and y HWP

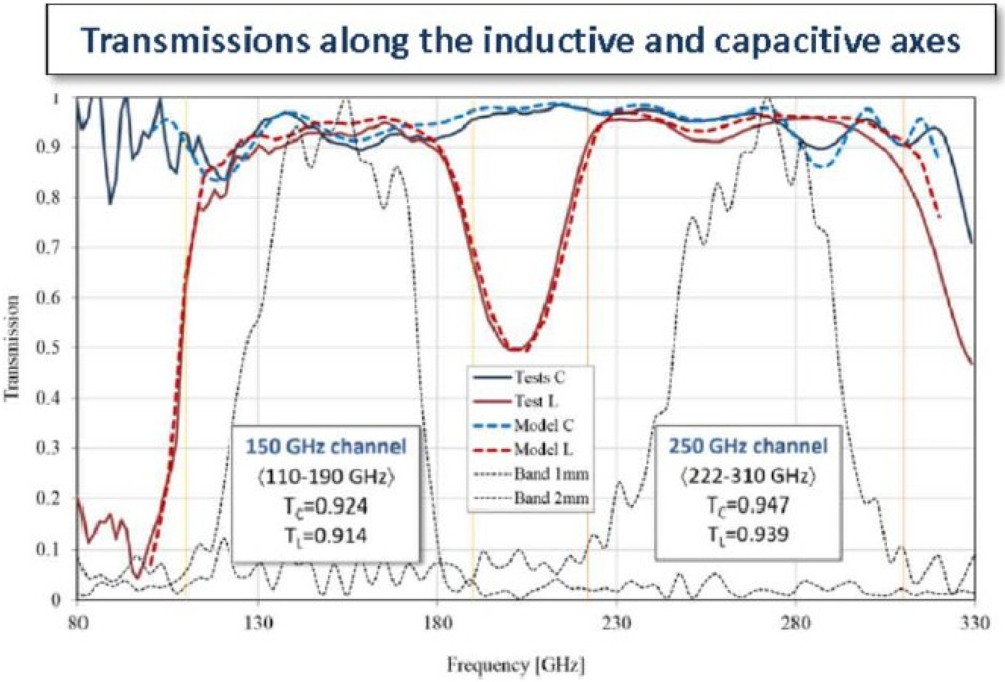


Made in Cardiff

- Challenges:
  - Large diameter thermal filters (> 0.5m)
  - Large diameter HWP (0.5m)
  - High bandwidth for HWP

- Solutions:
  - Manufacture with Quasi-optical meta-materials
  - Cardiff, provides filters for CMB polarizers in almost all the world
  - HWP based on mesh filter technology embedded with anisotropic mesh filters. Bandwidth 100% (3: 1) Axes defined photolithographically.

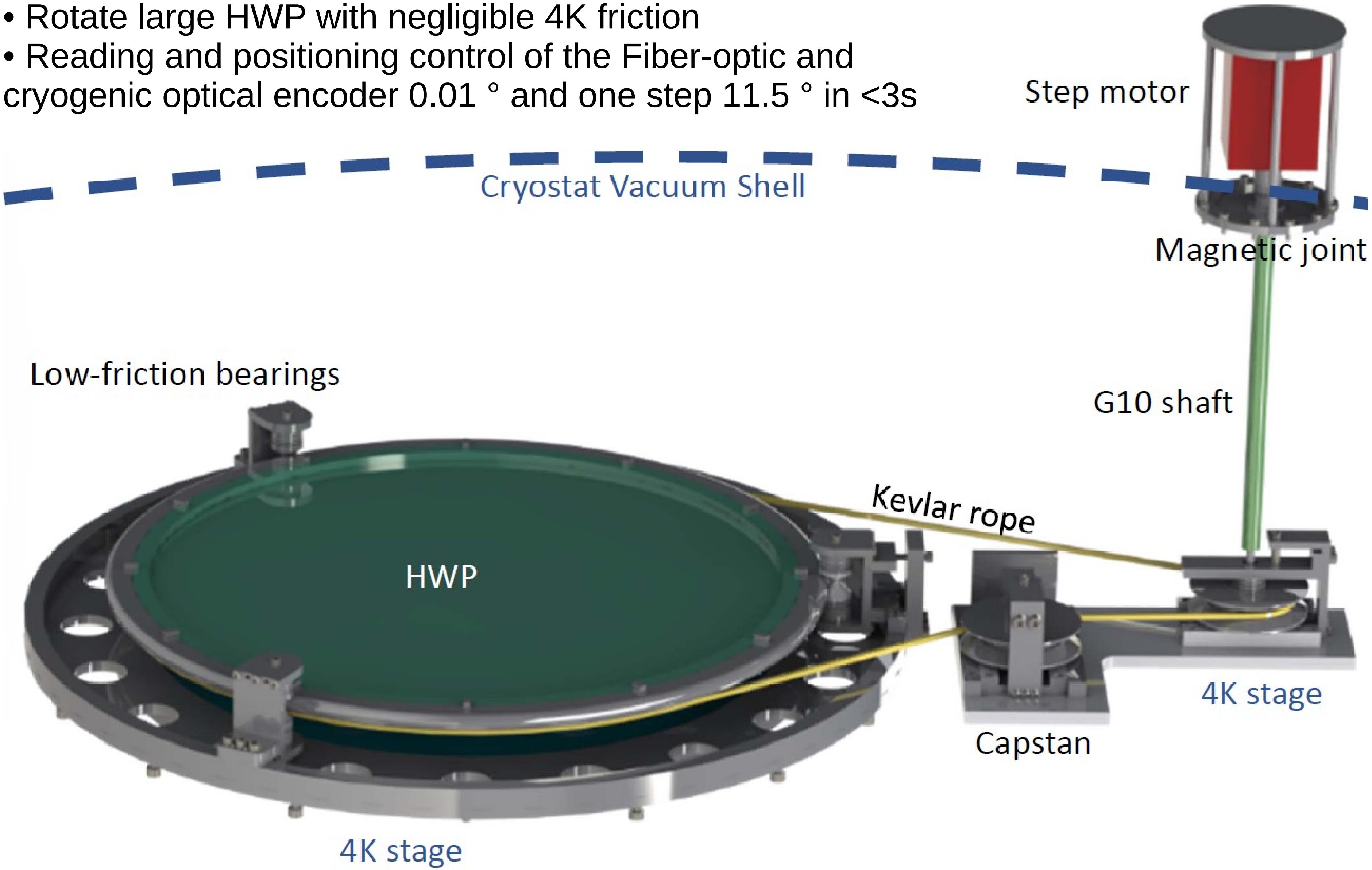




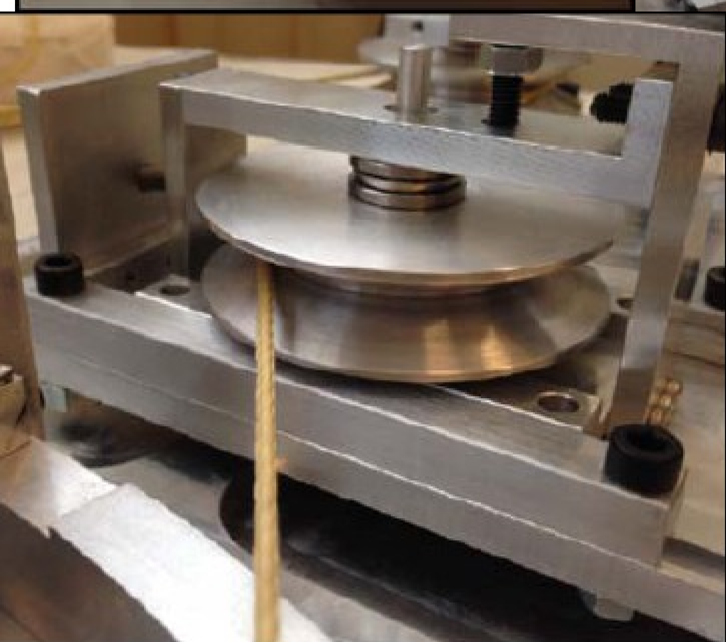
Cryogenic polarization modulator

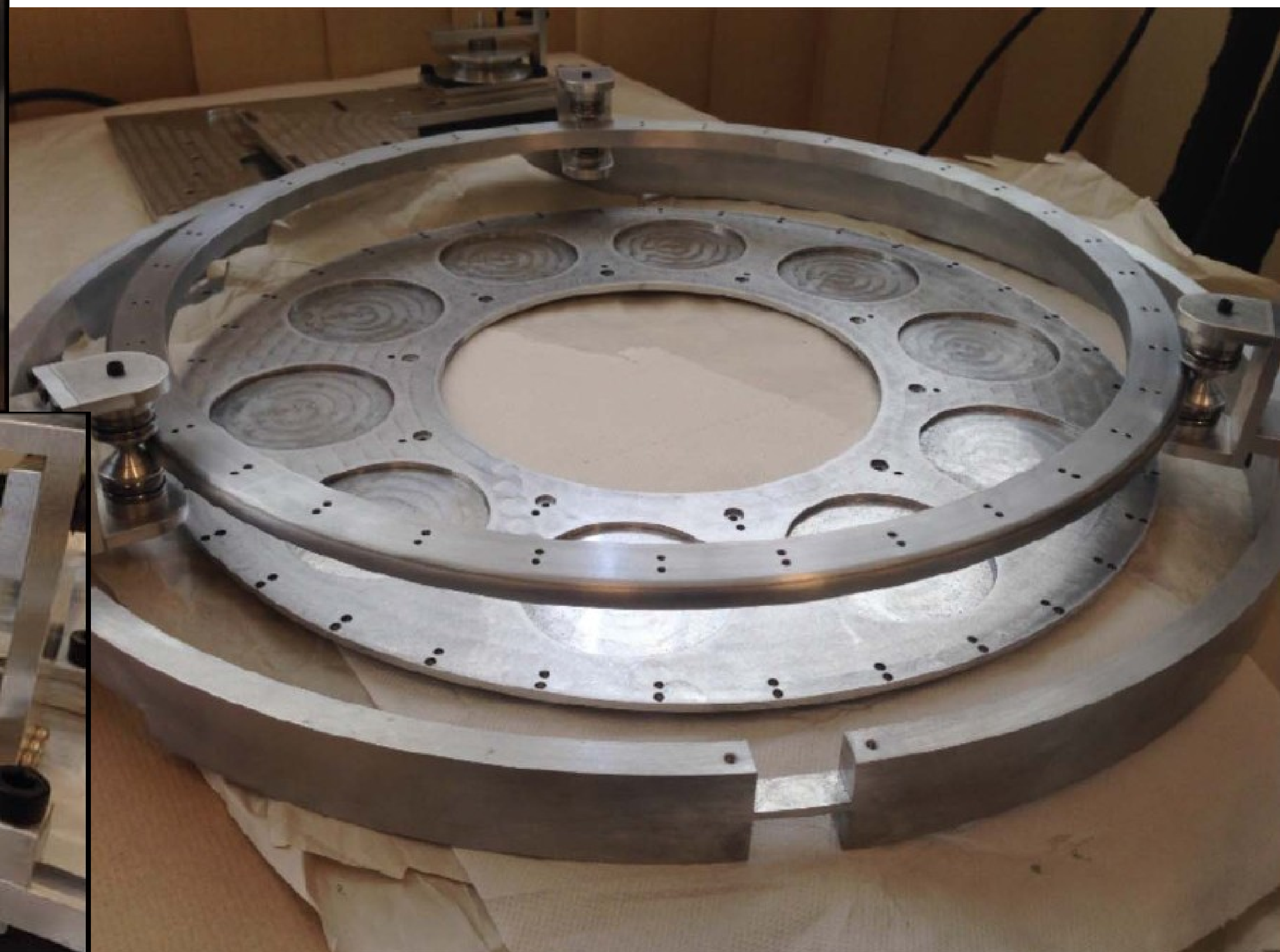
Made in Roma

- Rotate large HWP with negligible 4K friction
- Reading and positioning control of the Fiber-optic and cryogenic optical encoder 0.01 ° and one step 11.5 ° in <3s

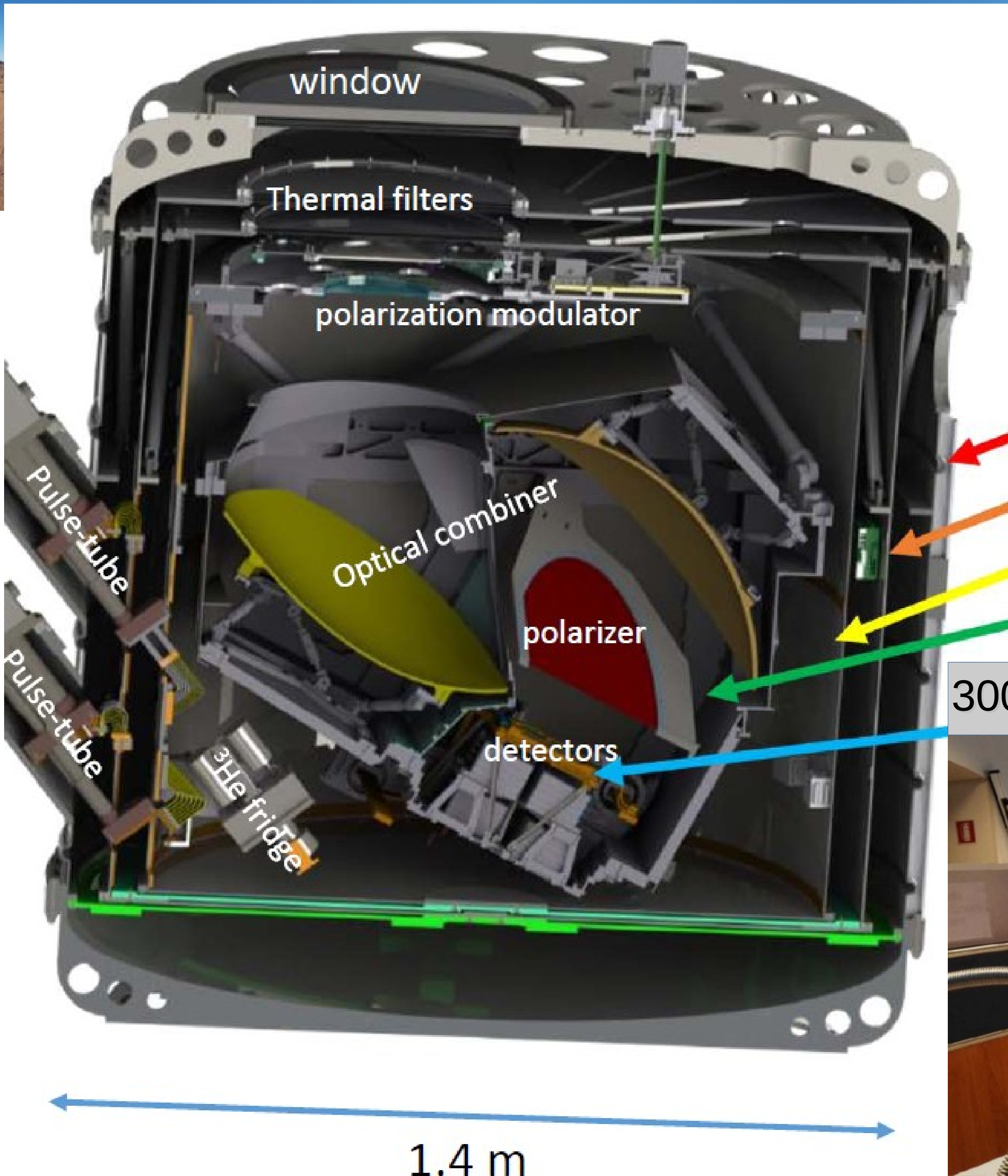


Cryogenic polarization modulator





Instrument



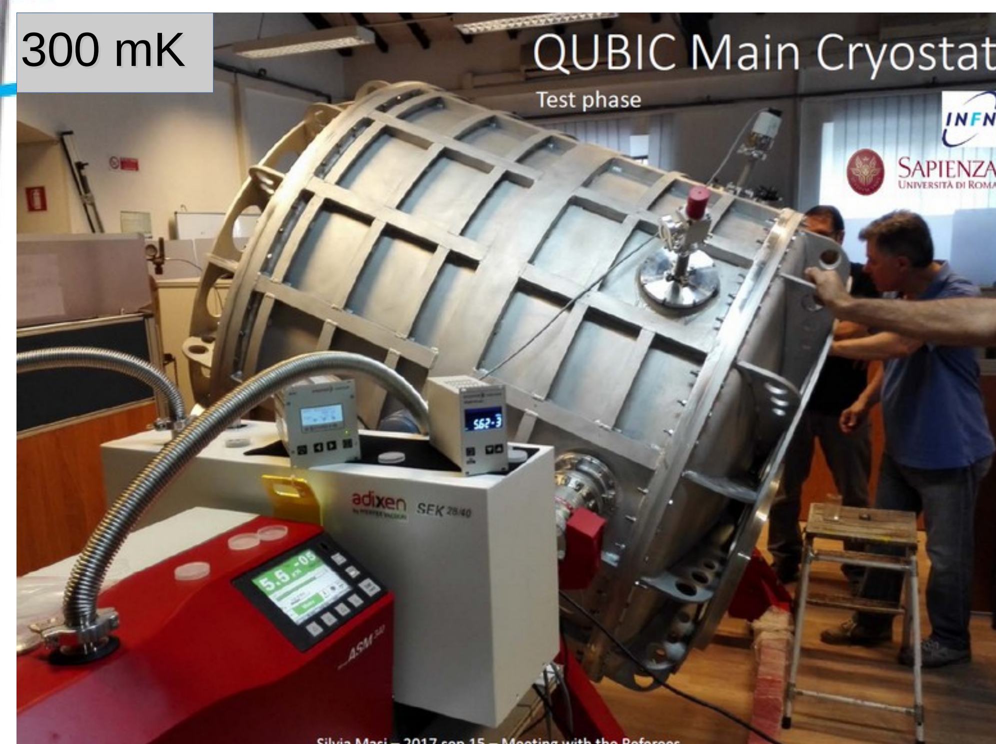
300 K

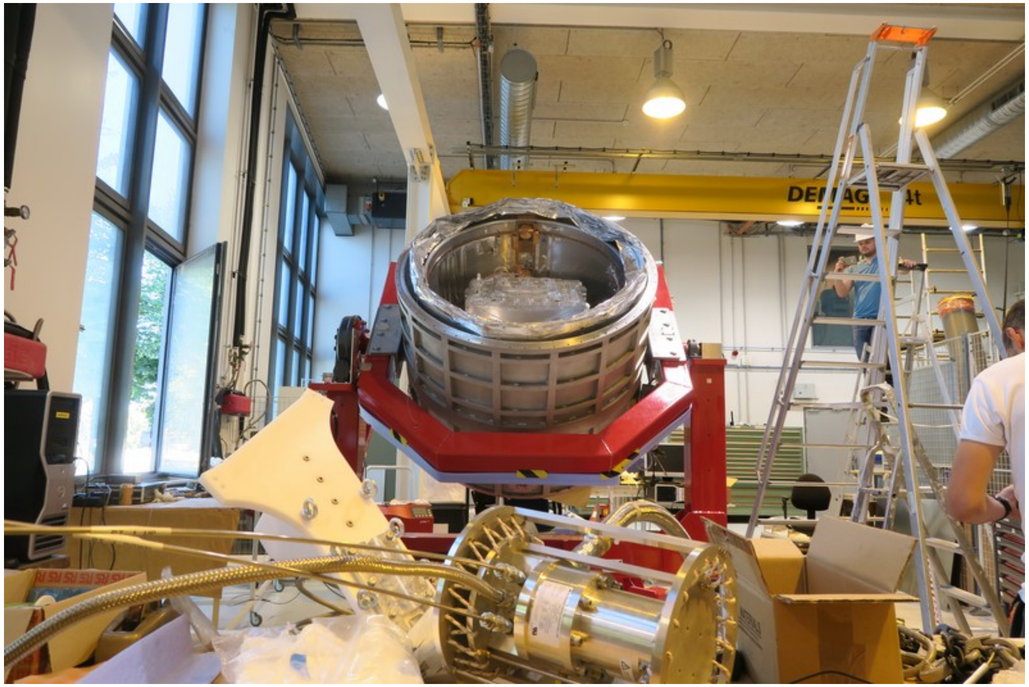
40 K

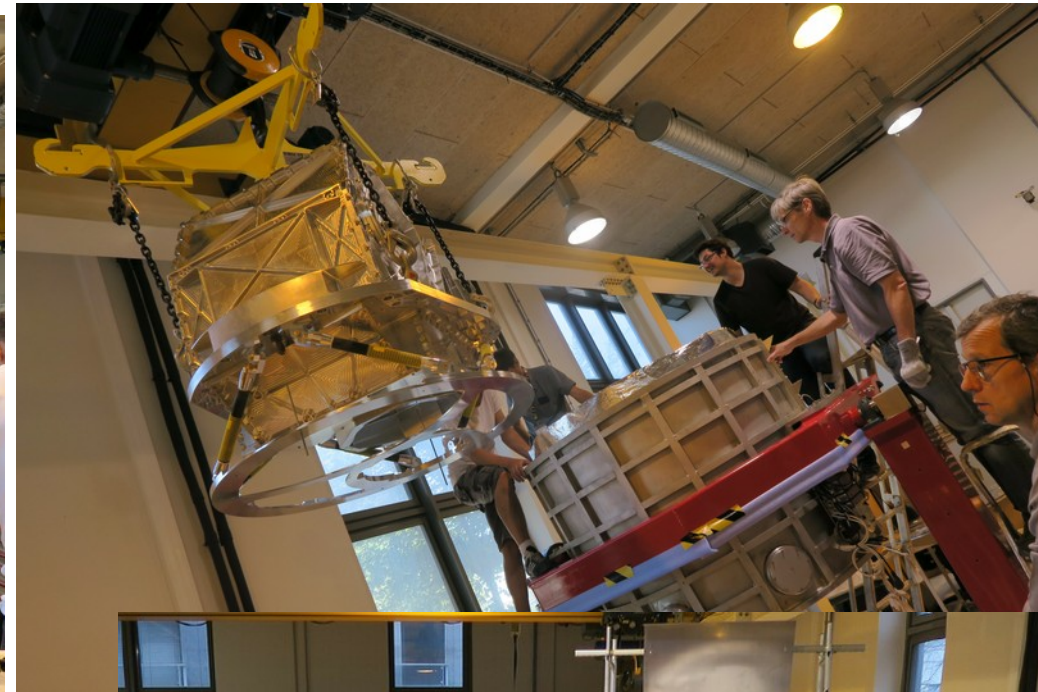
4 K

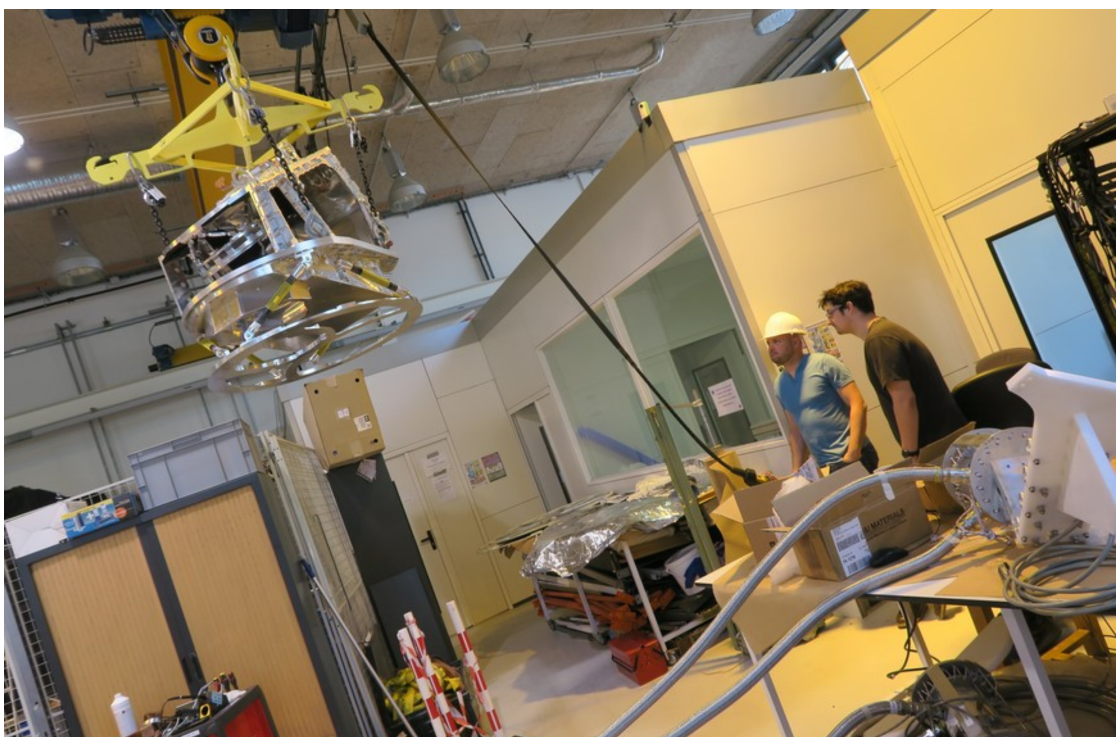
1 K

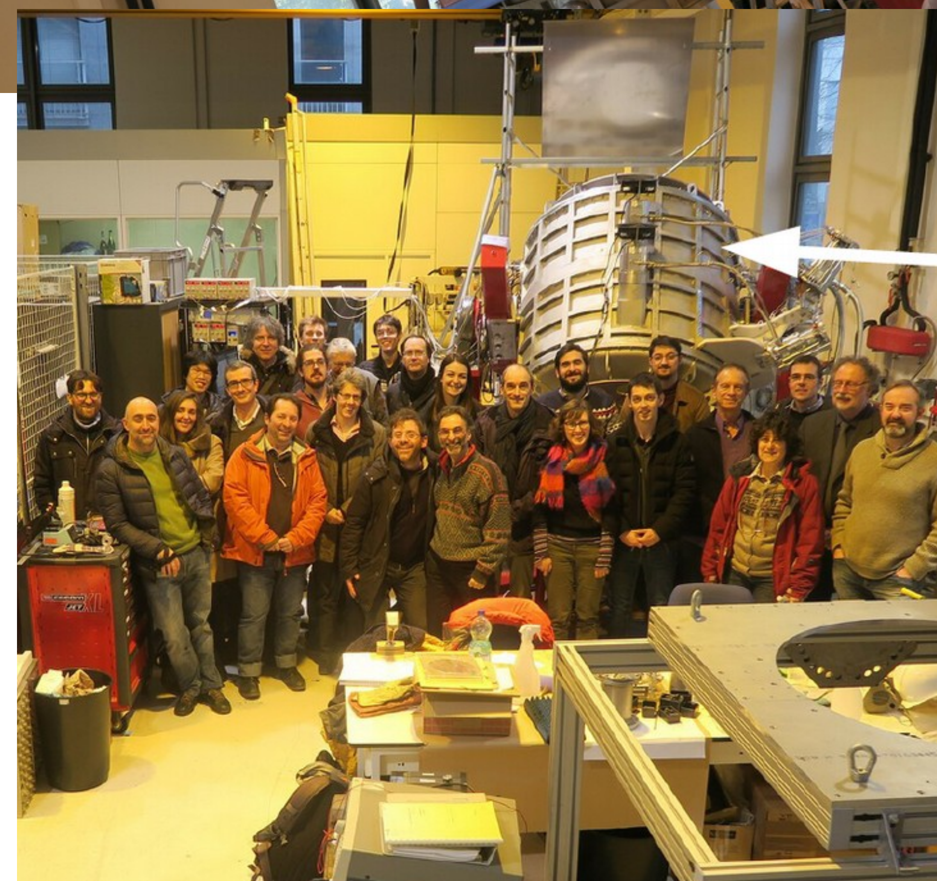
300 mK



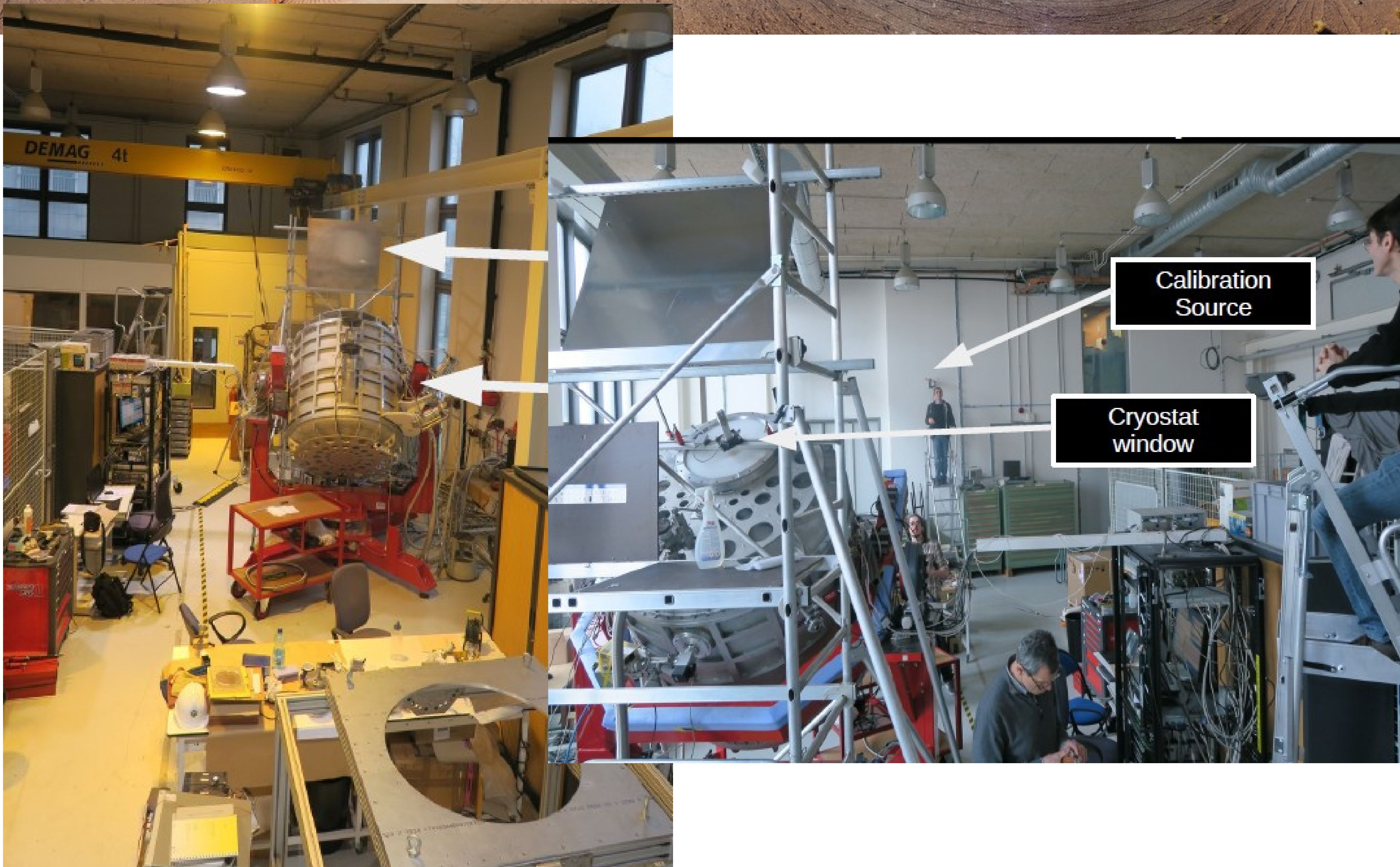


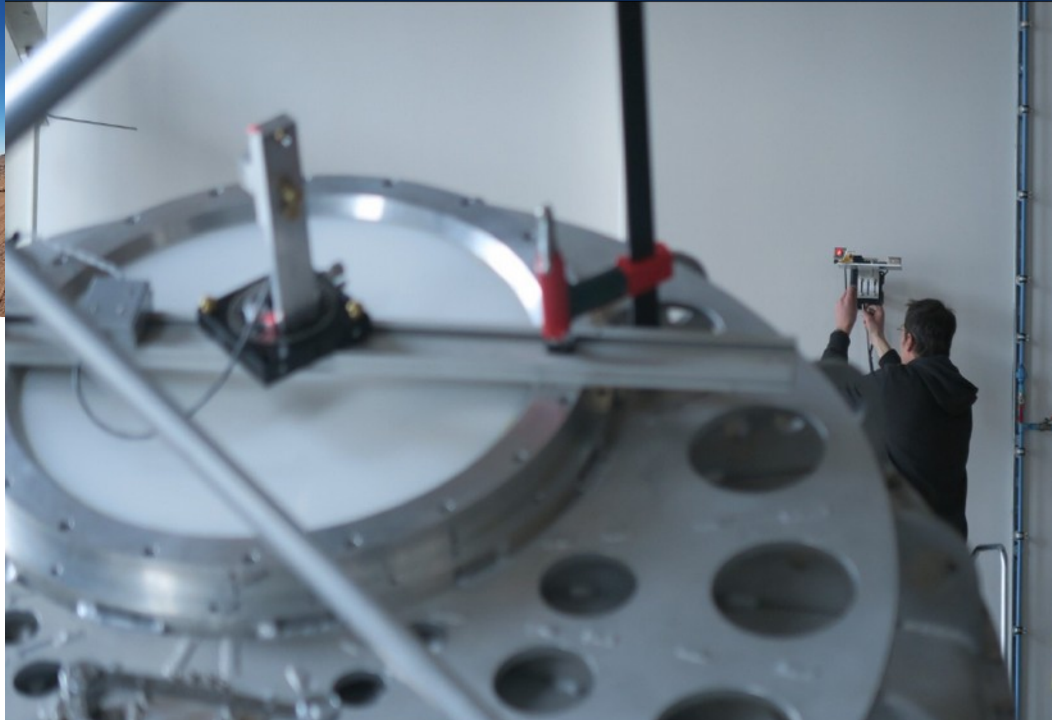


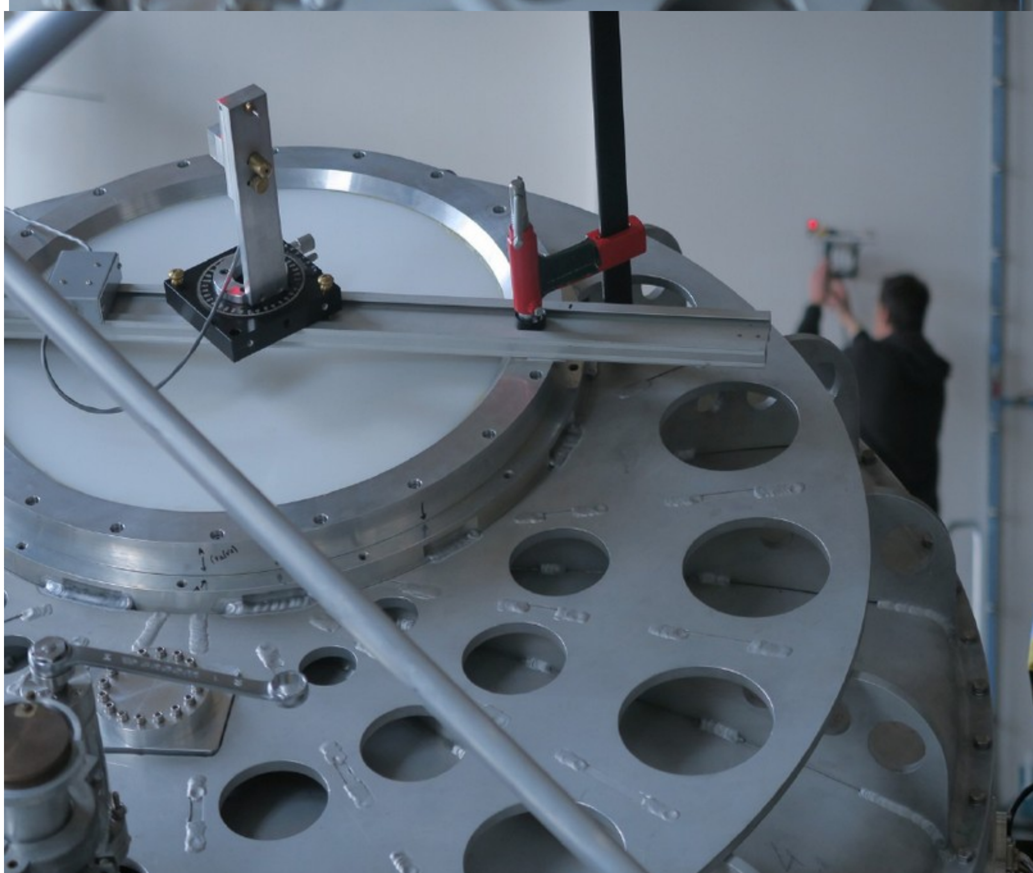


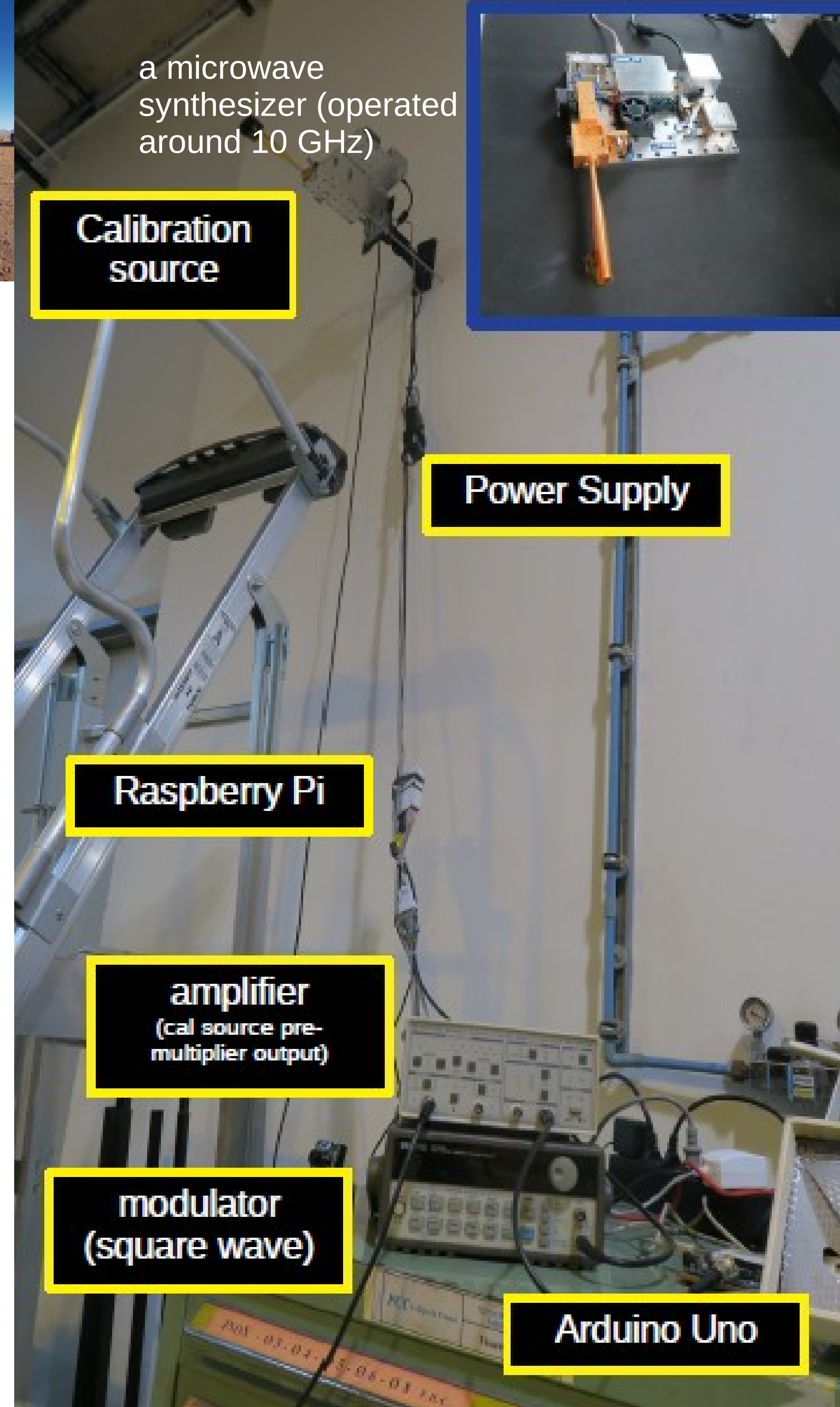


Callibration Setup

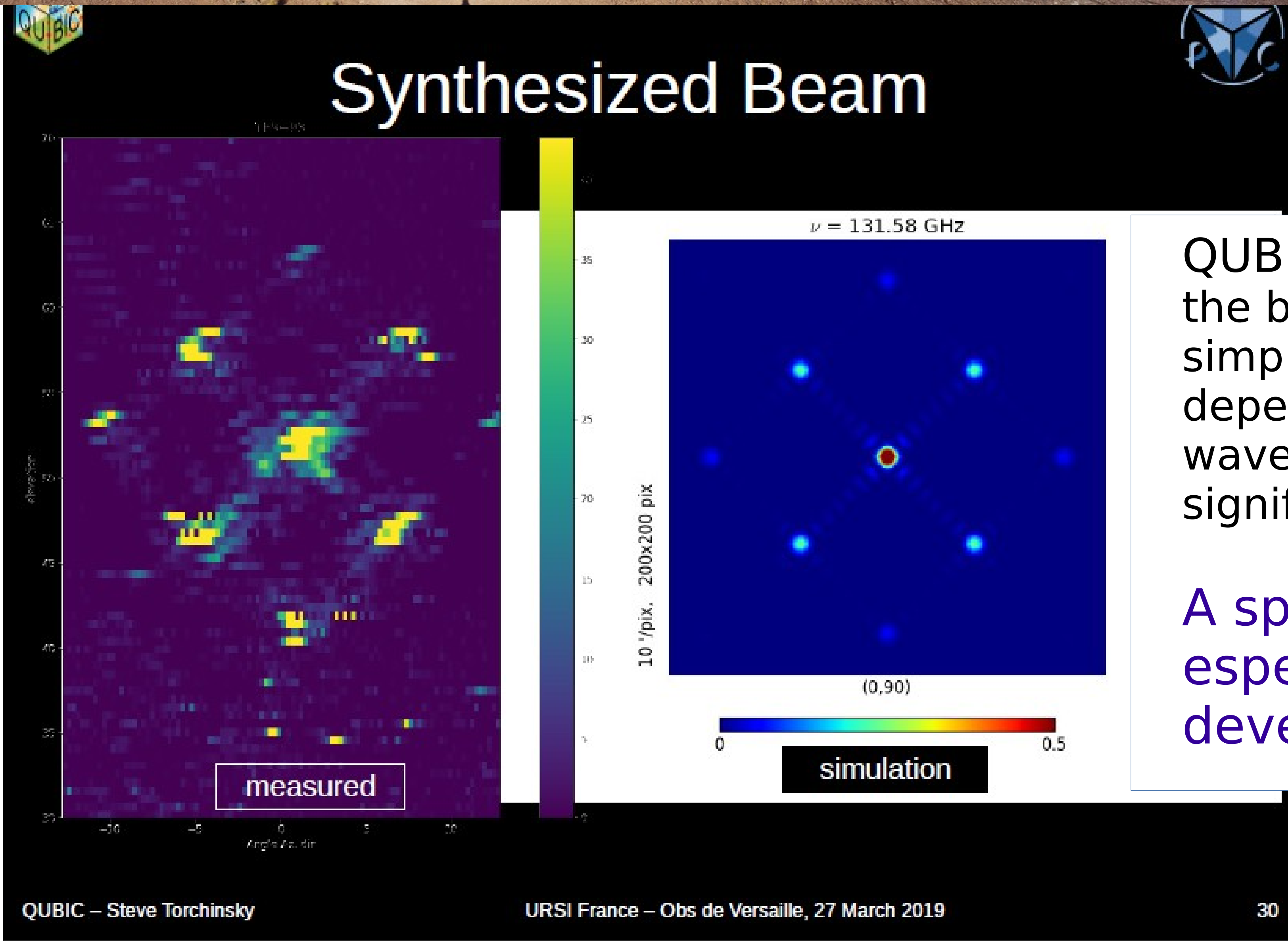







a microwave synthesizer (operated around 10 GHz)
Calibration source
Power Supply
Raspberry Pi
amplifier
(cal source pre-multiplier output)
modulator (square wave)
Arduino Uno

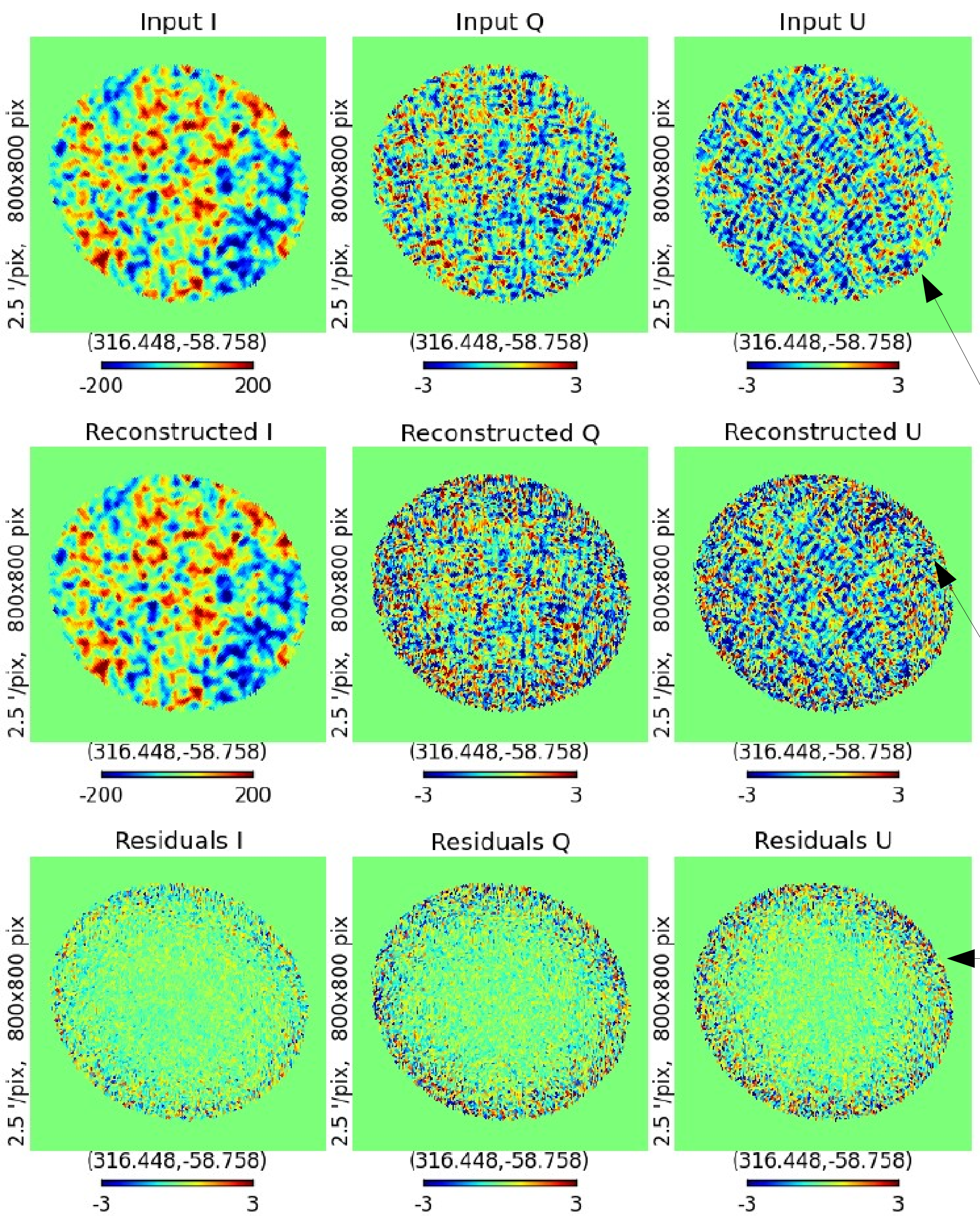
Simulations and data analysis



QUBIC is special: the beam is not simple and is dependent on the wavelength in a significant way

A special soft especial is being developed

QUBIC- data analysis



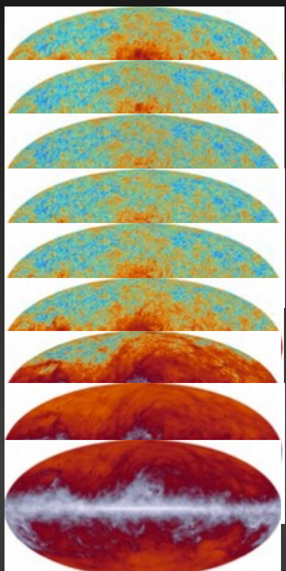
Current results of QUBIC mapping under the Gaussian peak hypothesis

Maps of I, Q and U in the region observed by QUBIC

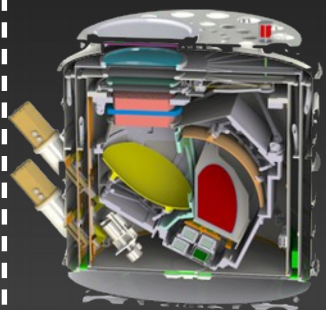
Reconstruction using the complete simuation pipeline

Residuals w.r.t. of the inicial maps

QUBIC Spectro-Imaging



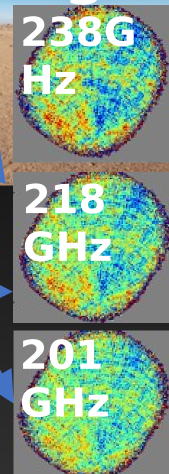
Sky:
« Infinite # bands »

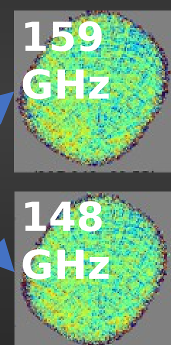


TOD(220 GHz)

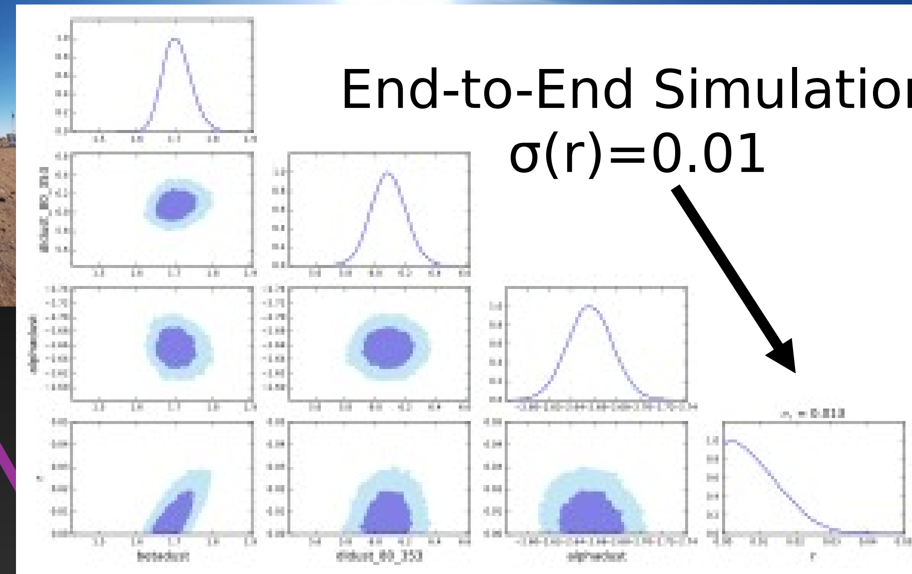
TOD(150 GHz)

Instrument:
2 broad-bands

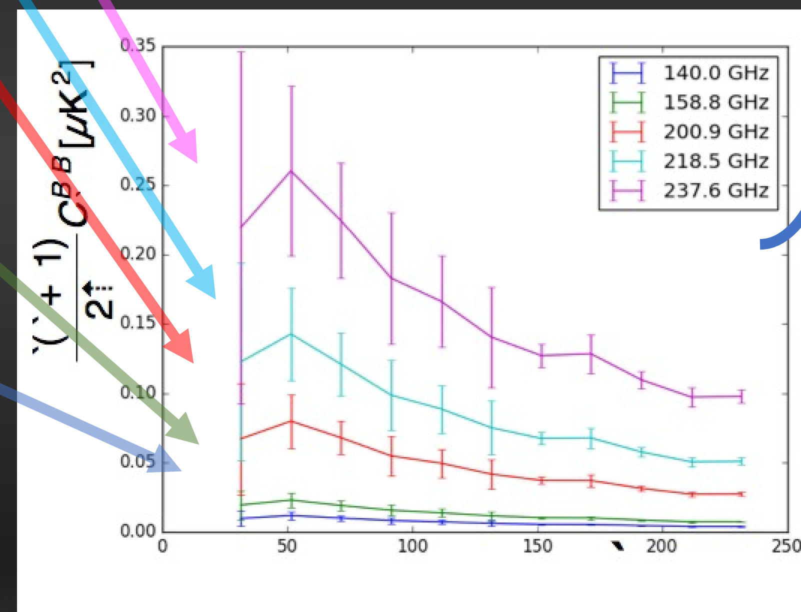




Data analysis:
5 narrow-bands



End-to-End Simulation
σ(r)=0.01



=> better spectral resolution
=> sustraction of the dust

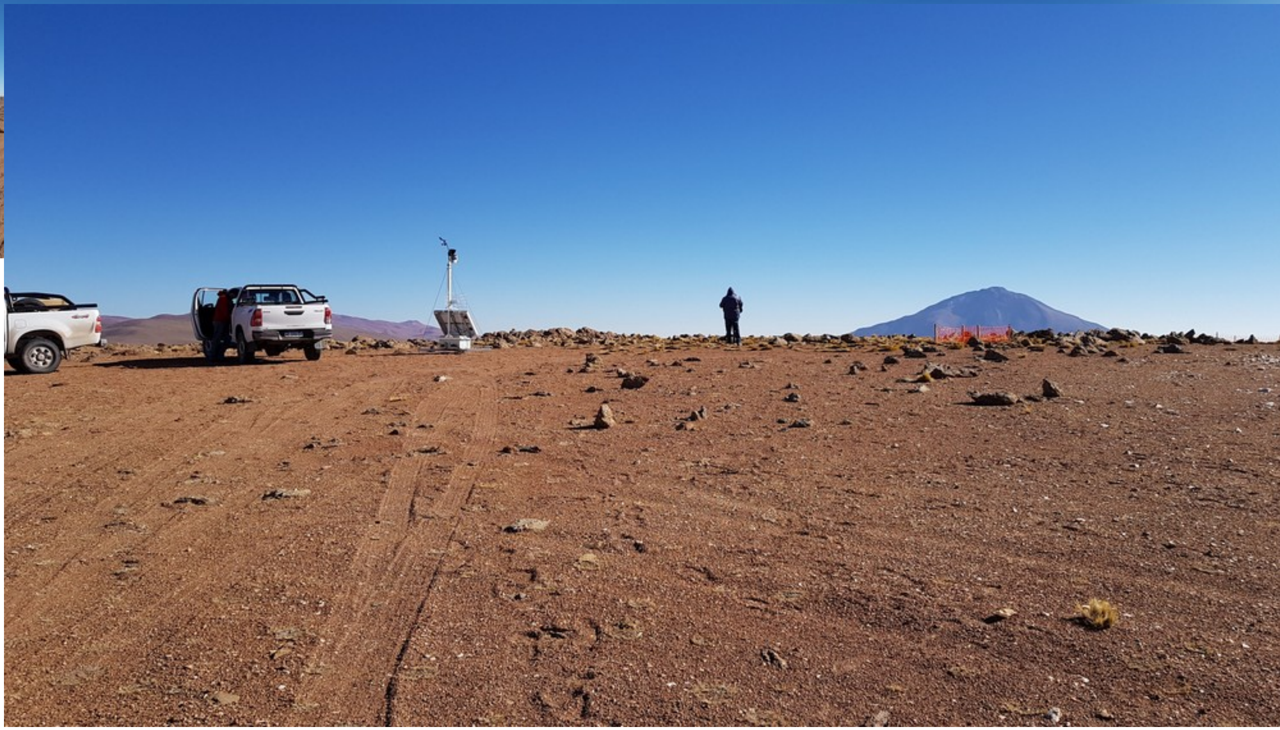
Calibration

Very important.
Several steps:

- **In Paris Lab** (validation before shipment)
- Standard calibration:
Detector performance, eficiency

- **In Salta Lab**

- **On site**
- Internal simulator that illuminates the focal plane
- Calibration Tower: coherent source in the far field will be observed for a significant fraction of time of the auto-calibration time, made at APC Paris
- Sky source

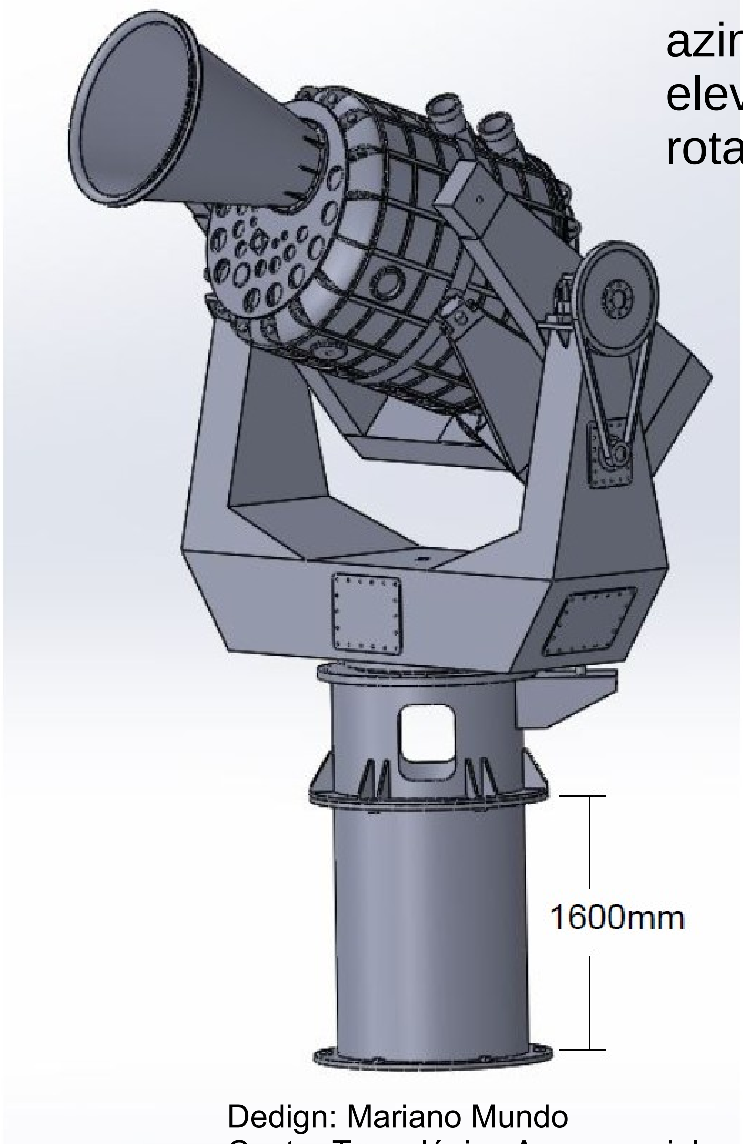


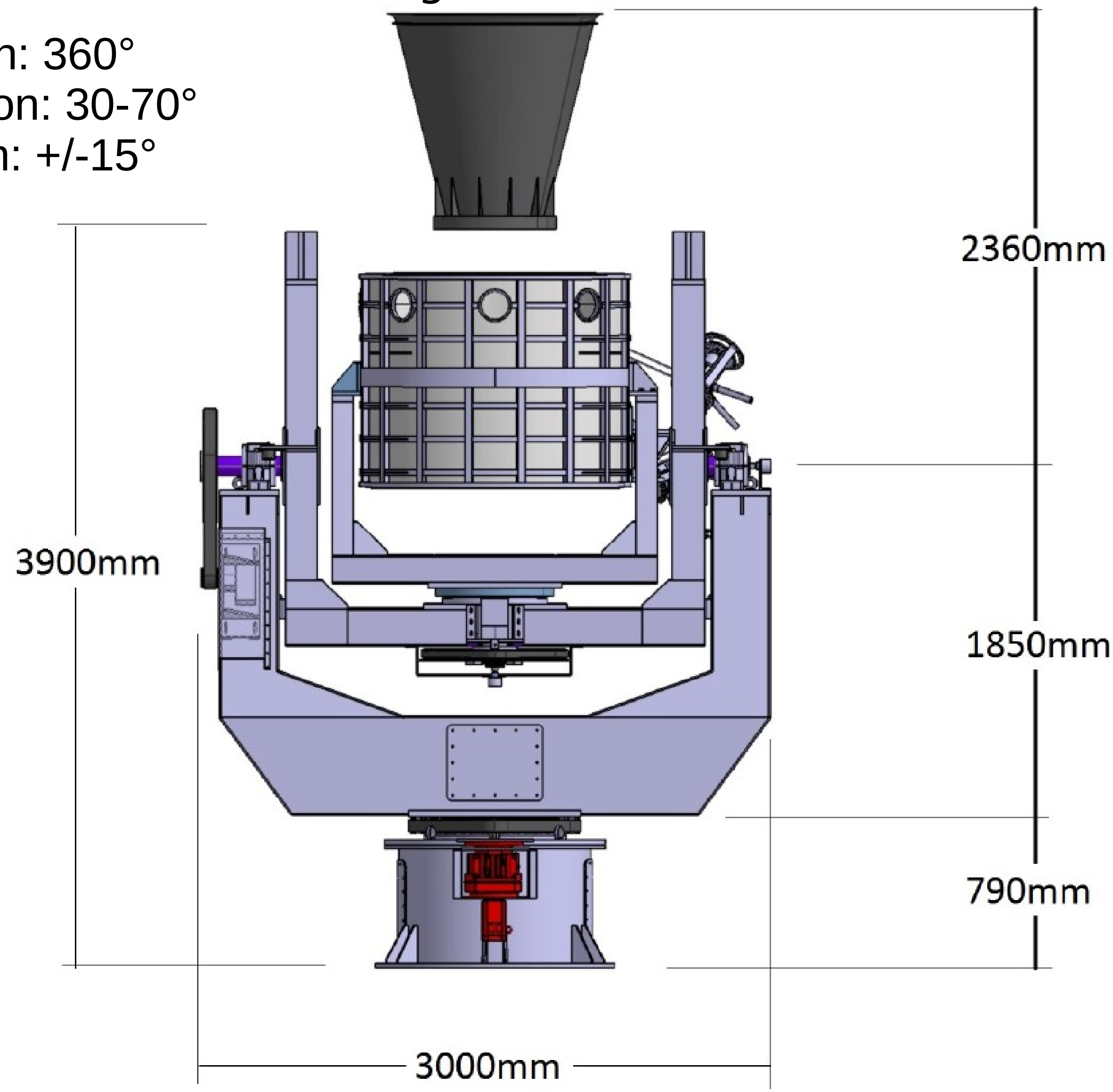


Mount

Alt - Az mount with additional rotation movement around the optical axis to treat systematic effects. To be manufactured in Argentina

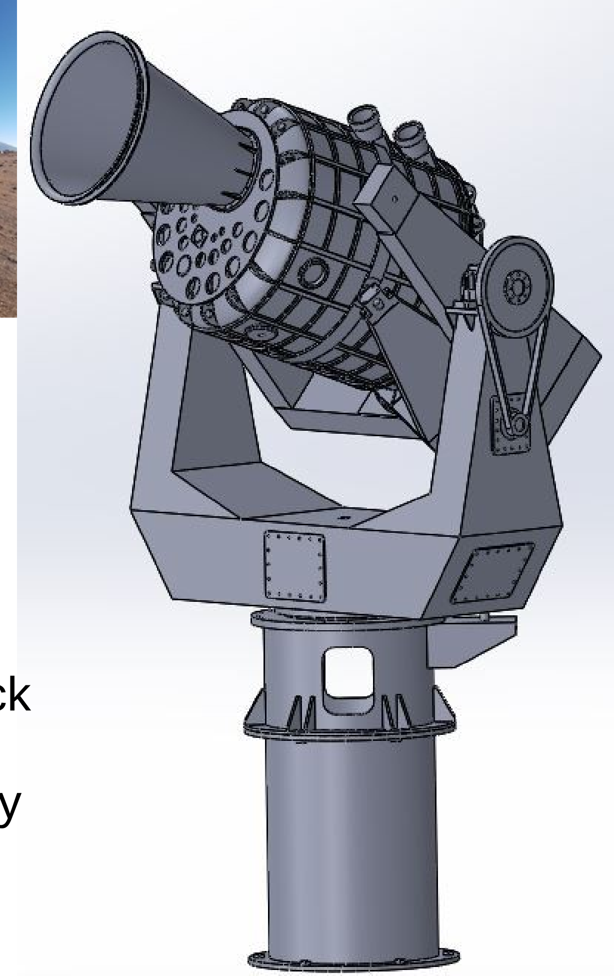
azimuth: 360°
elevation: 30-70°
rotation: +/-15°



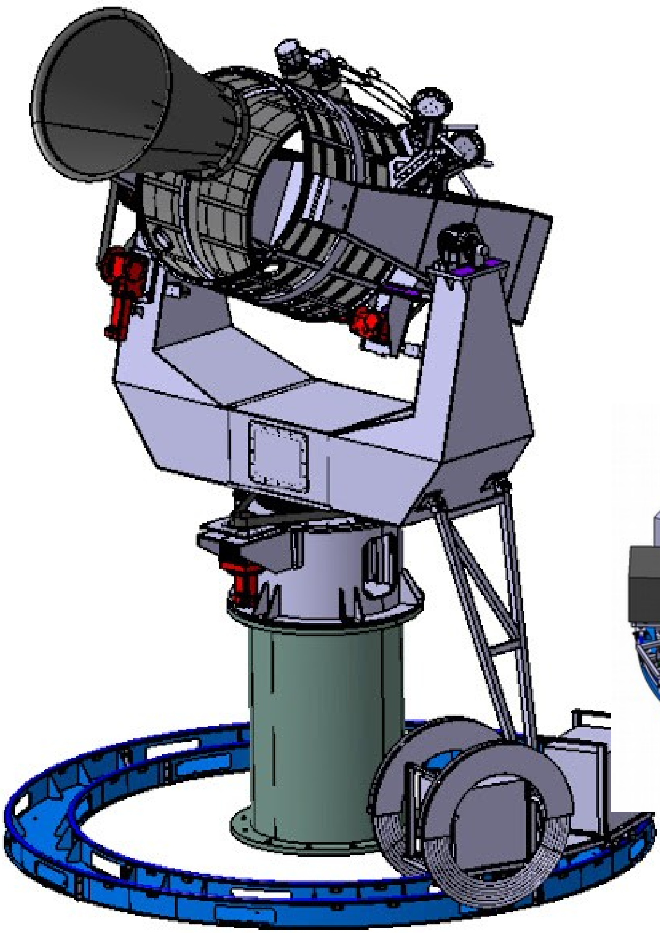


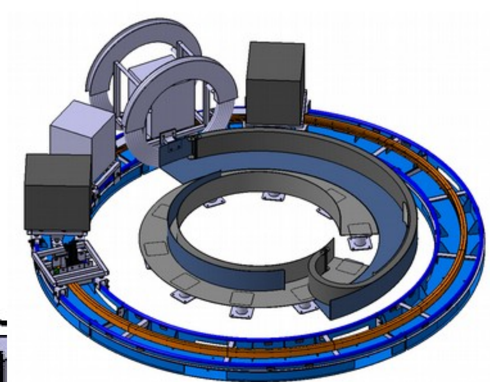
Dedign: Mariano Mundo
Centro Tecnológico Aeroespacial (CTA) Grupo de Ensayos Mecánicos Aplicados (UID-GEMA)

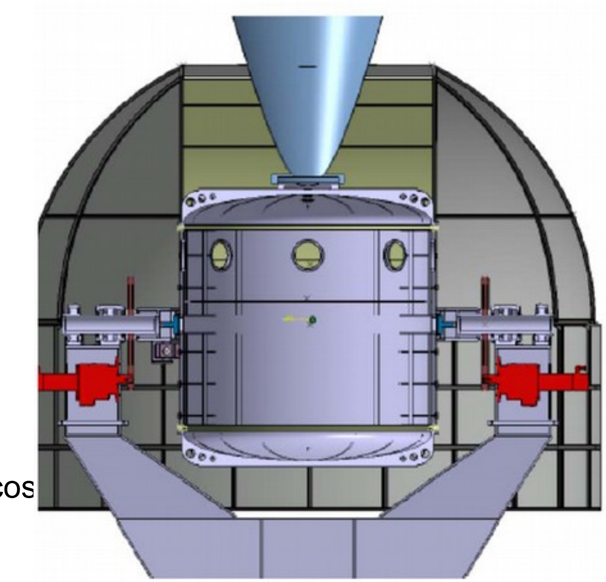
Mount



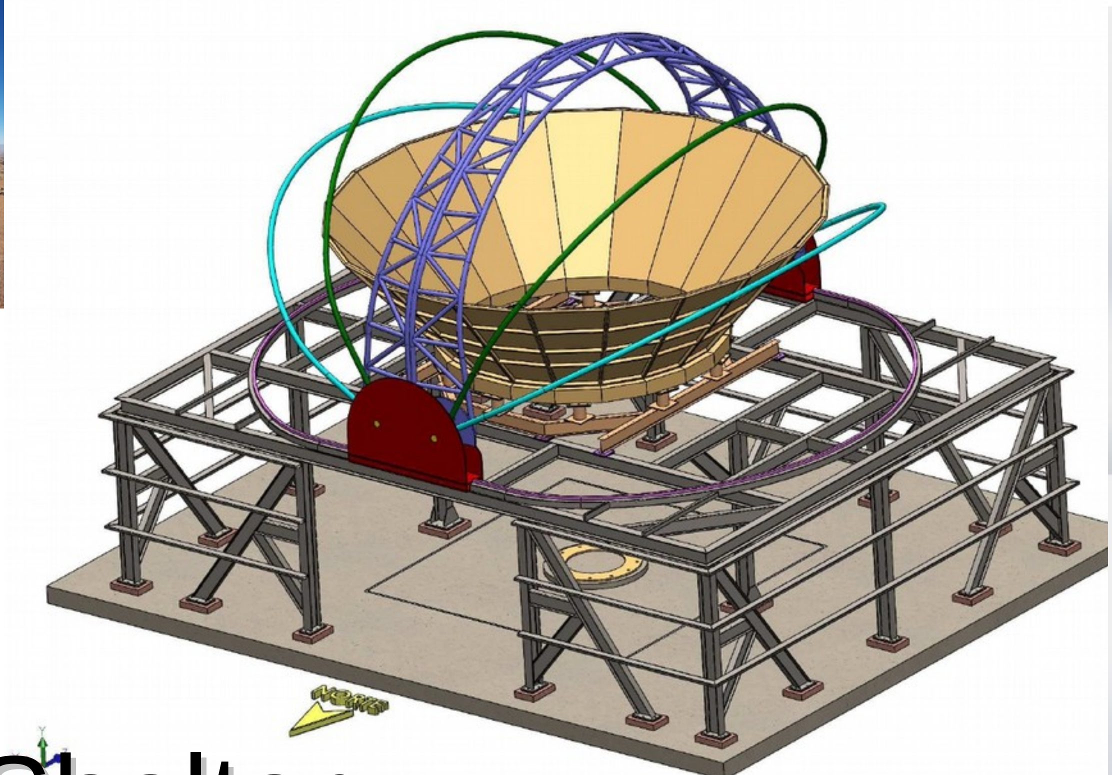
Rail:
1 locomotive
2 for compressors
2 for standard 19 "rack
for all QUBIC
electronics not directly
linked to cryostat



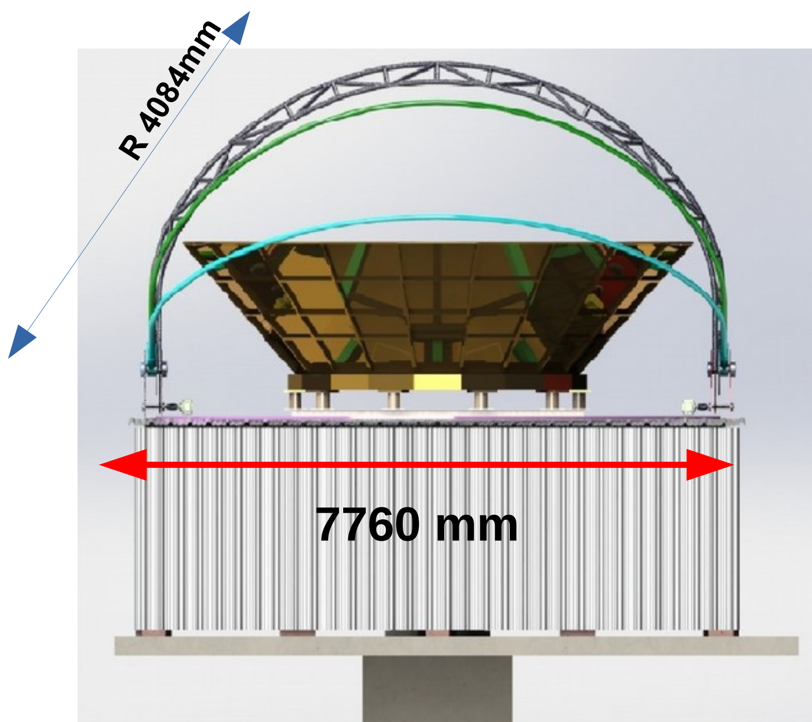


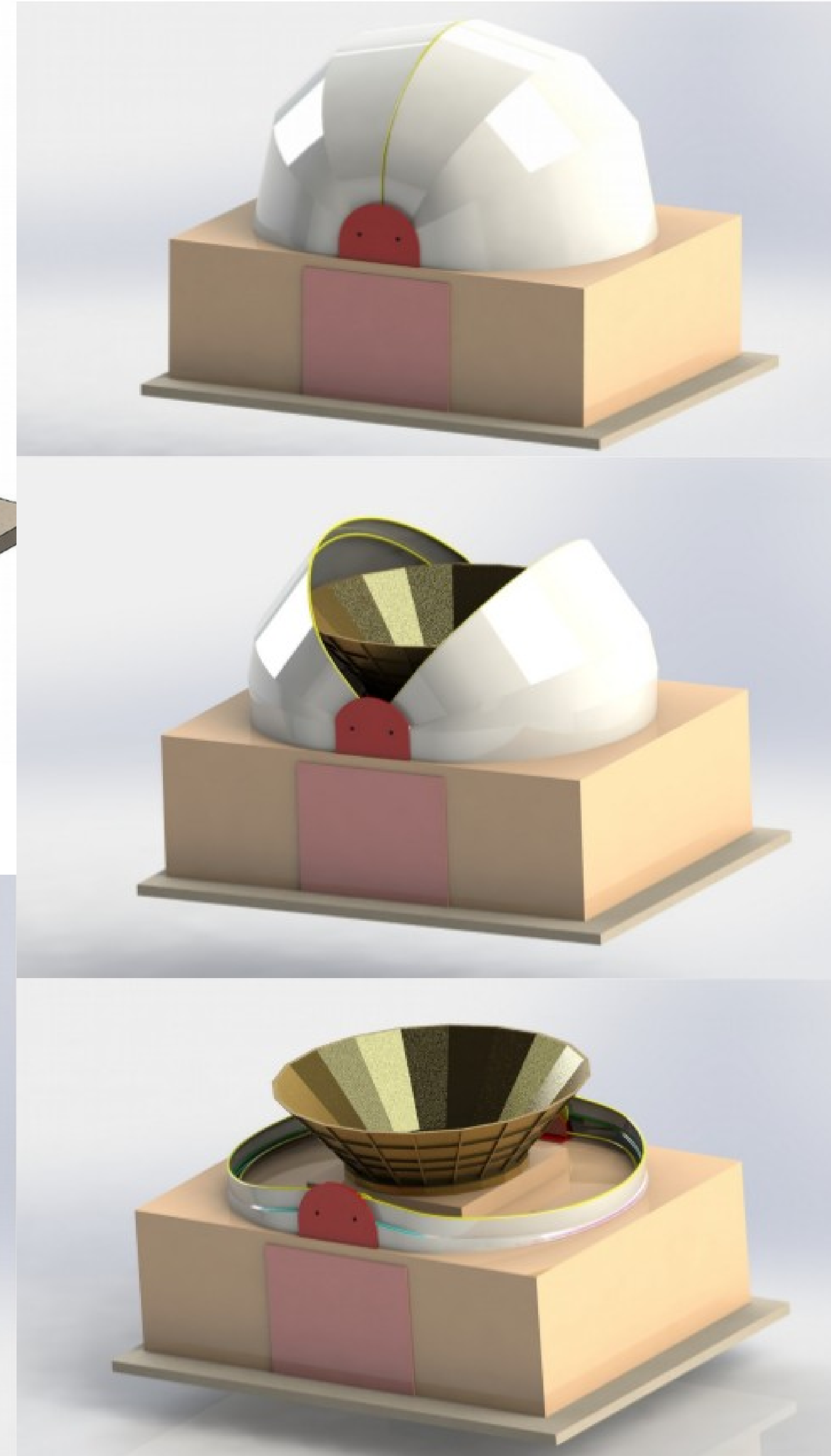


Design: Mariano Mundo
Centro Tecnológico Aeroespacial
(CTA) Grupo de Ensayos Mecánicos
Aplicados (UID-GEMA)

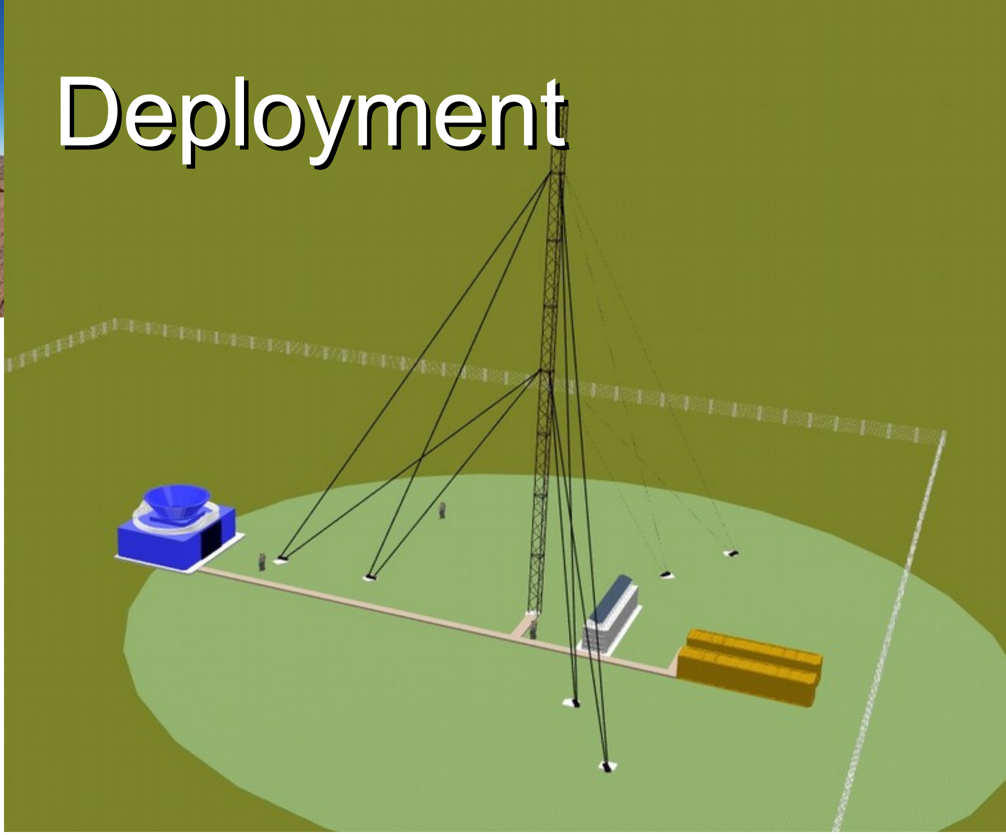


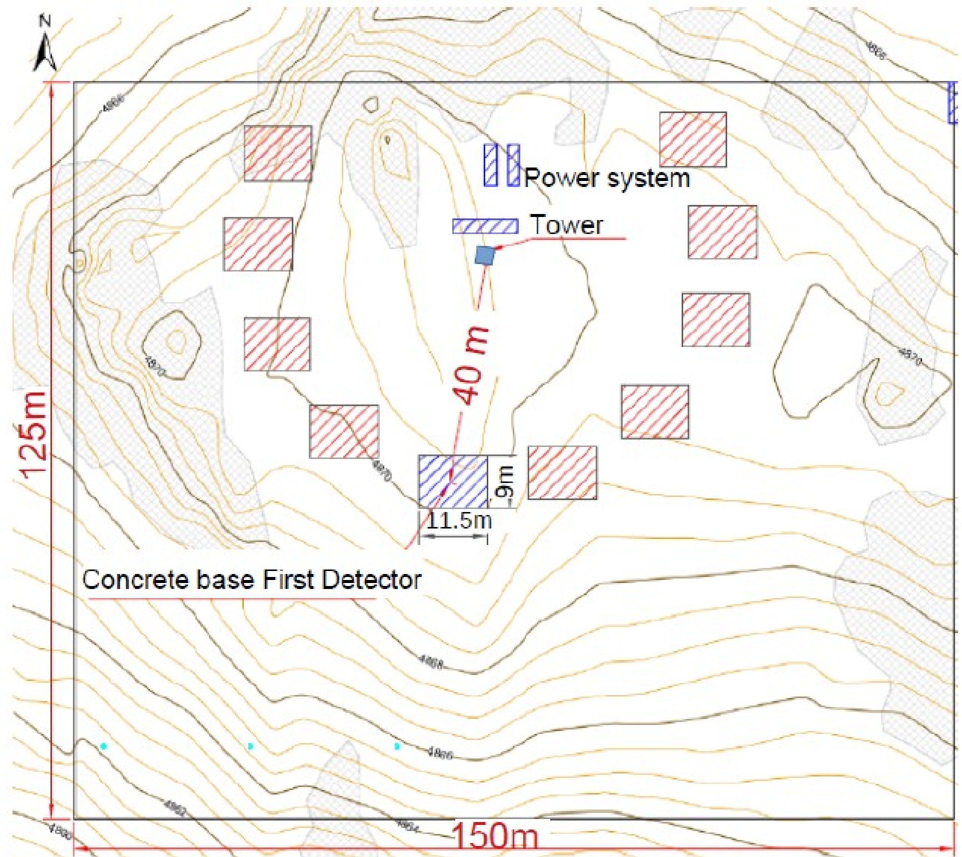
Shelter and dome



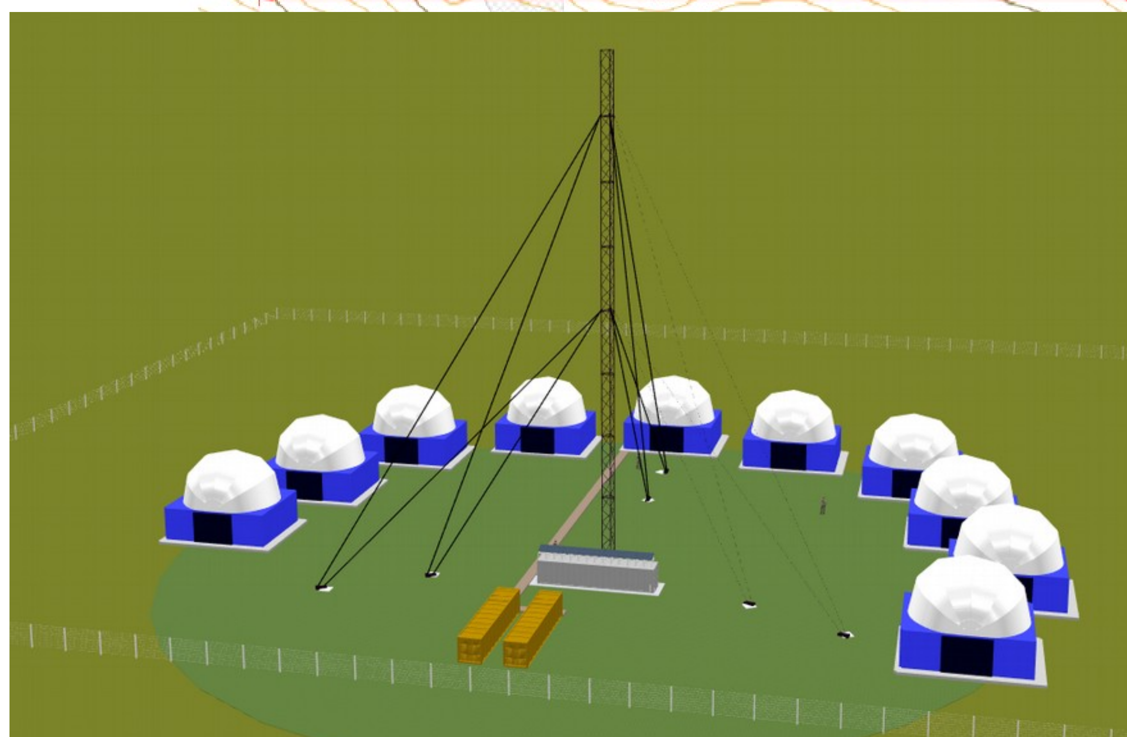


Deployment





Módulo	Frec (GHz)	Comienzo	Fin
1	150/220	2017	2025
2	150/220	2019	2025
3	90	2020	2025
4	120	2021	2025
5	220	2022	2025
6	90	2023	2025



Schedule: 3 steps

- Focal Plane testing: 2016
  - ★ 256 TES in Lab
  - ★ 128:1 Multiplexing

Validation of the Detection Chain ✔

- Technological Demonstrator:2018-2019
  - ★ Nominal criostate8x8 horns Array
  - ★ Reduced Mirros
  - ★ 256 TES / frecuencia
  - ★ Lab testing

Technology Validation ✔

- QUBIC 1rs Module: 2020
  - ★ 400 horns array
  - ★ Nominal Mirros
  - ★ 1024 TES / frecuency
  - ★ Testing in Lab
  - ★ Instalation and first light

Search of B-mode $\sigma(r) = 0.01$ in 2year ✔

Conclusion

- **Installation in Argentina of a frontier experiment in cosmology.**
  A novel technique to control systematics.
  Argentine participation (IAR, ITeDA, CAB, IB, IAFE, UNLP), important international collaboration (France, Italy, UK, USA,...).

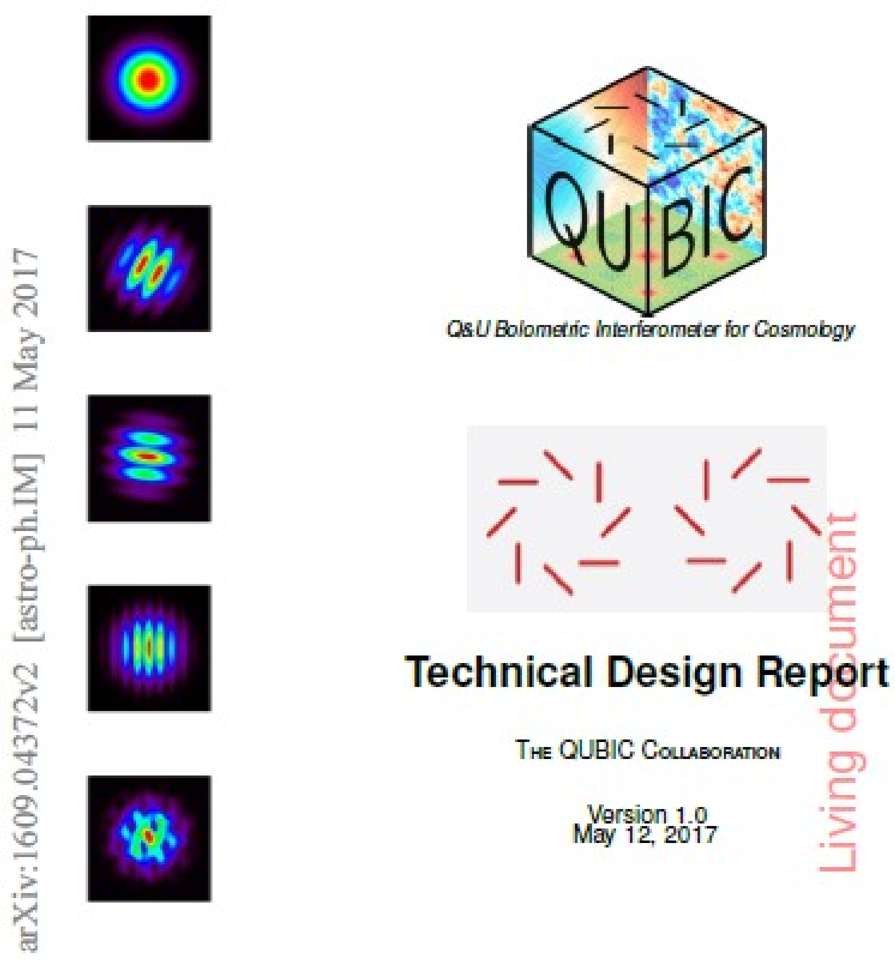
instalation 2020/2021

- **Development of Alto Chorrillo site:**
  A new scientific / astronomical pole where LLAMA is located
  New project can take advantages of the site development

- **High International impact**
  Measurement of prime B modes would have huge international public impact.

- **Human Resources: new detection technologies and software**

5 PhD theses in progress



arXiv:1609.04372v2 [astro-ph.IM] 11 May 2017

QUBIC

Q&U Bolometric Interferometer for Cosmology

Technical Design Report

The QUBIC Collaboration

Version 1.0
May 12, 2017

Living document

Thank you
for your attention

Presupuesto

		Cost	Available	Missing	Who ?
QUBIC Instrument	Instrument (no Mount)	1 820 000 €	1 550 000 €	270 000 € (Detection Chain + Source)	IN2P3 / INSU
	Mount	500 000 € (est. NIKHEF)	300 000 € (NIKHEF OK)	200 000 €	Argentina ?
	Total	**2 320 000 €**	**1 850 000 €**	**470 000 €**	**Netherlands / Other ?**
QUBIC Exploitation	Logistics (Dôme C)	~ 750 000 €		~750 000 €	IPEV / PNRA Other site (Argentina) ?
	Scientific Exploitation	450 000 €		450 000 €	ANR / Other ?
	Total	**1 200 000 €**		**1 200 000 €**	
Total	Total	3 520 000 €	1 850 000 €	1 670 000 €	