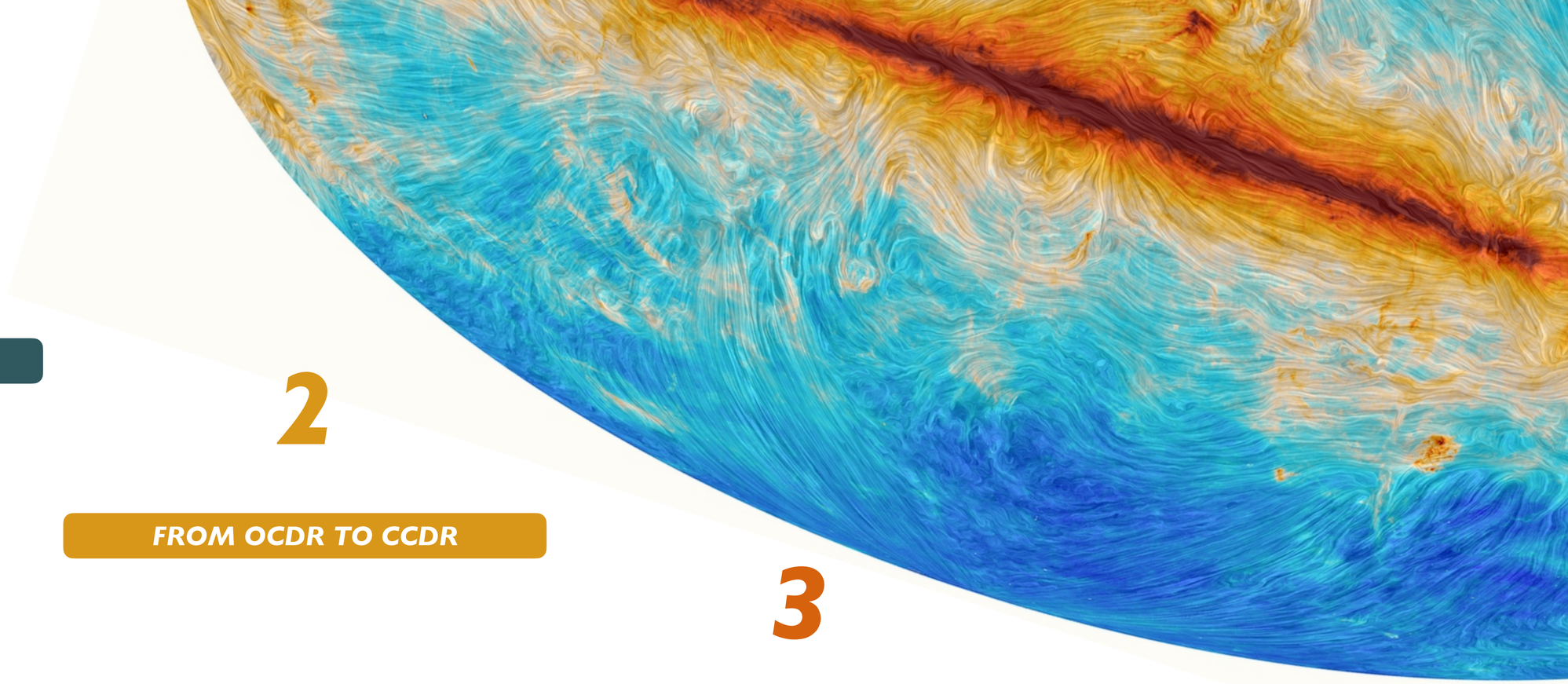
Institut d'Astrophysique Spatiale
Orsay

École Doctorale d'Astronomie & Astrophysique
d'île-de-France

Elbereth 2021

Development of a Closed Cycle Dilution Refrigerator for future astronomical missions

Valentin SAUVAGE



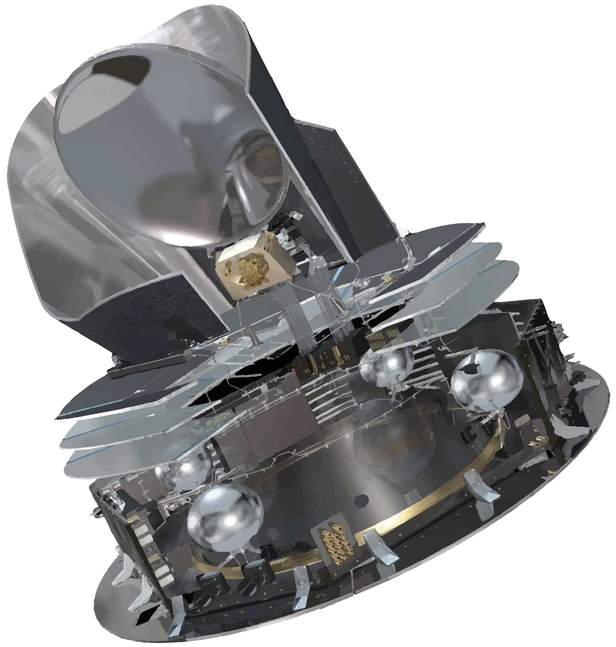
Planck Results

1

CMB OBSERVATIONS

2

FROM OCDR TO CCDR



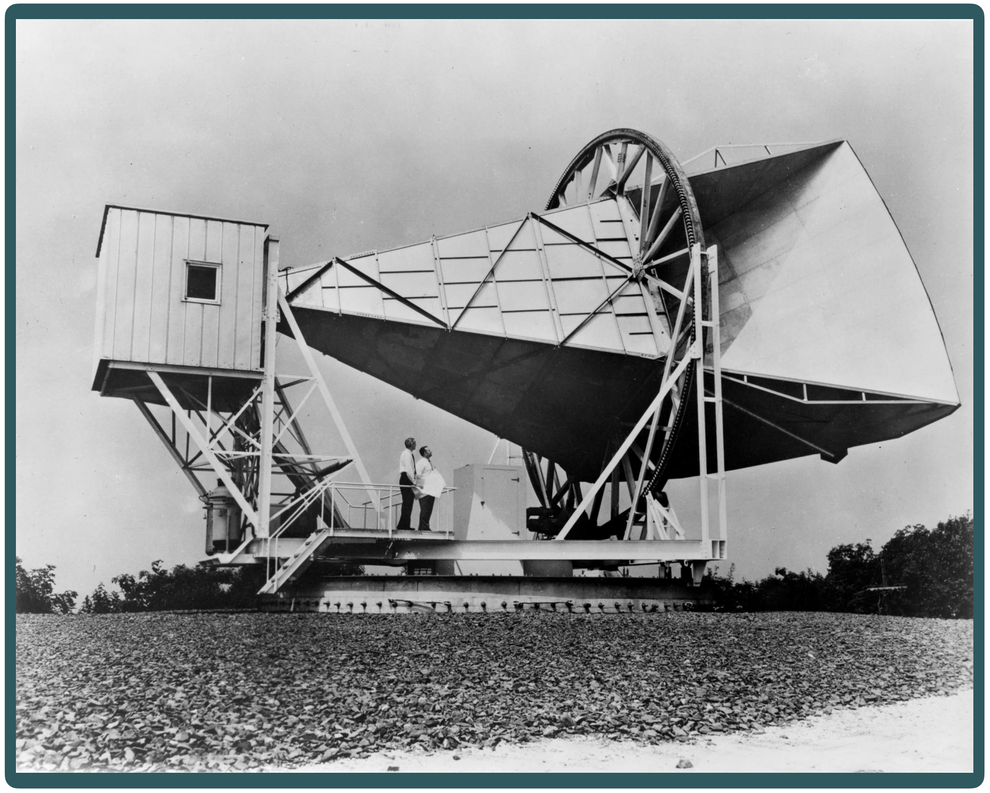
3

SYSTEMATIC EFFECTS

4

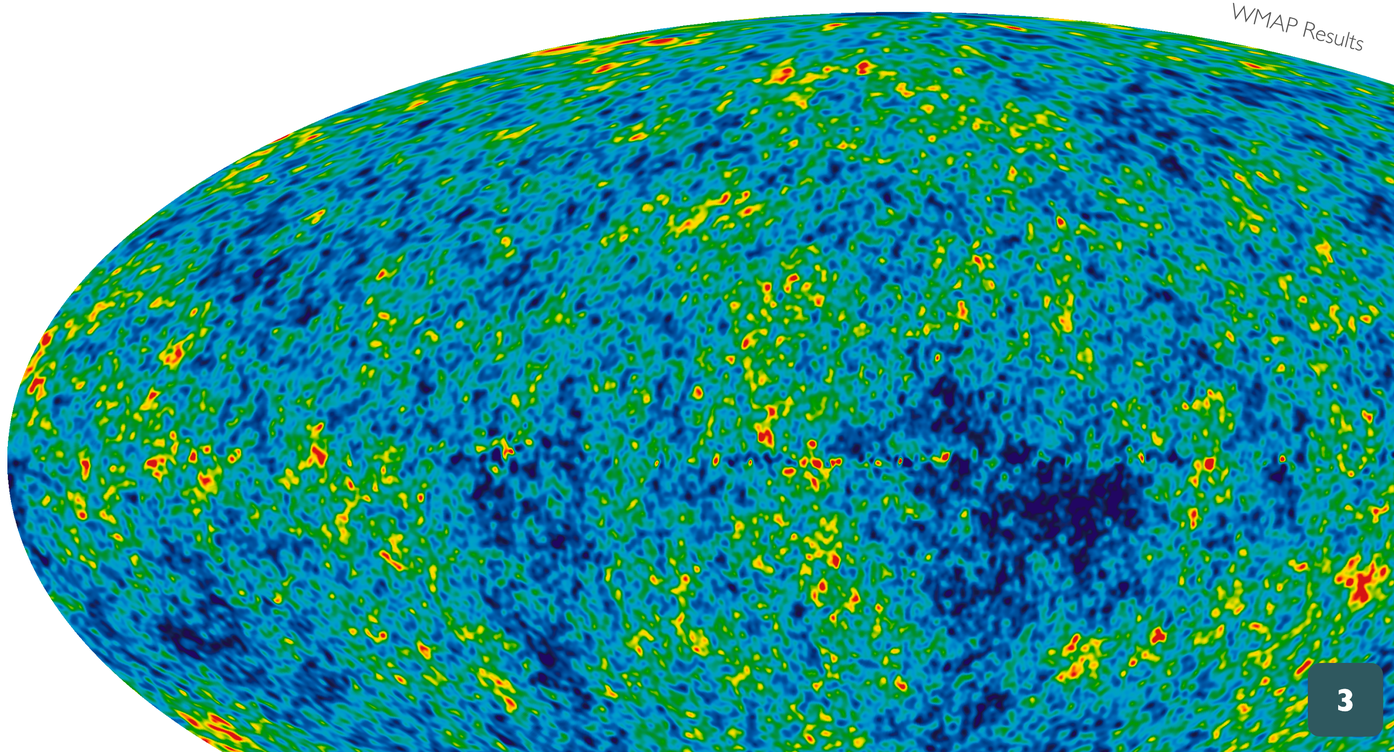
FUTURE FOR CCDR

Cosmic Microwave Background : predicted and observed



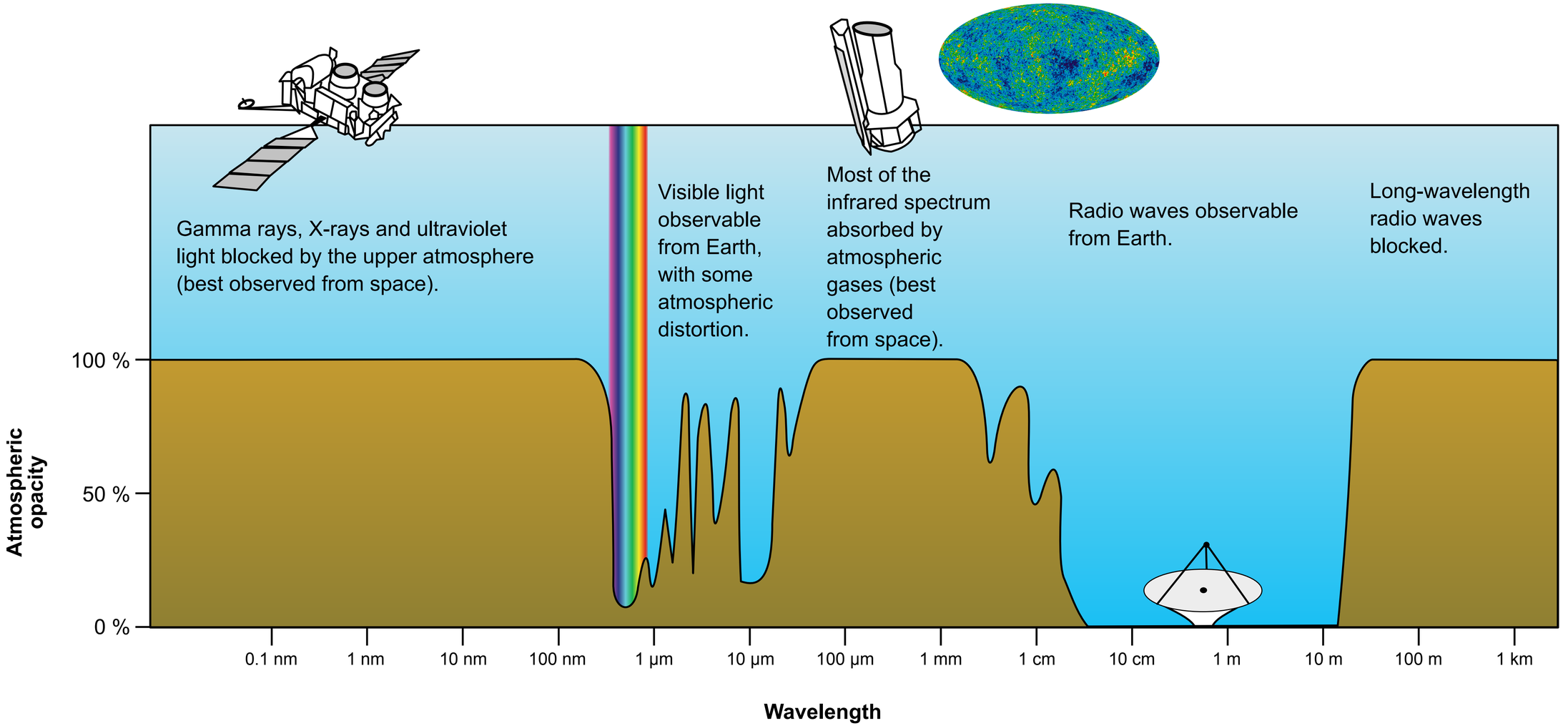
Par NASA — Great Images in NASA Description,, https://commons.wikimedia.org/w/index.php?curid=6463768

Penzias & Wilson in 1964
First CMB observation



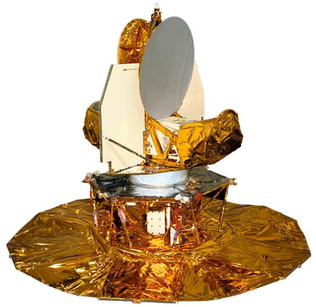
WMAP Results

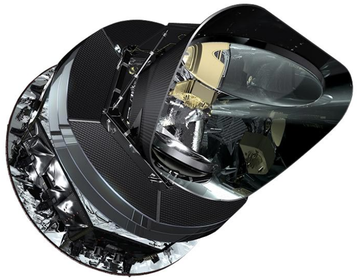
Ground observations ?

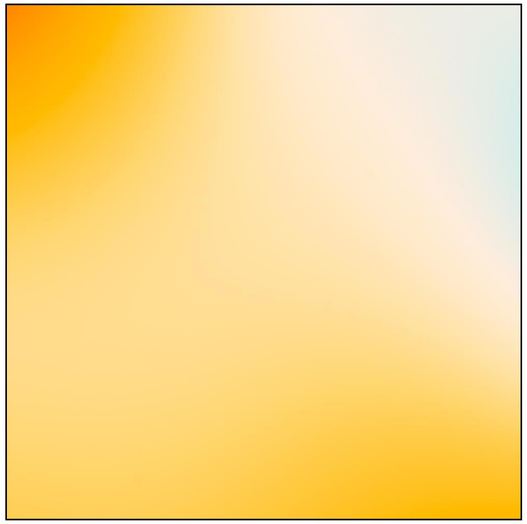


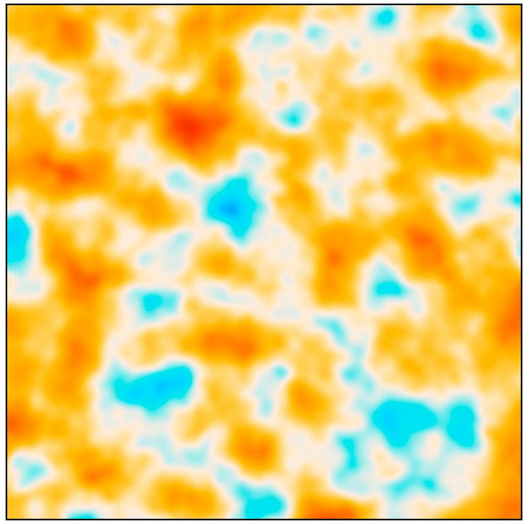
Atmospheric absorption percentages throughout the electromagnetic spectrum. Image Credit: NASA

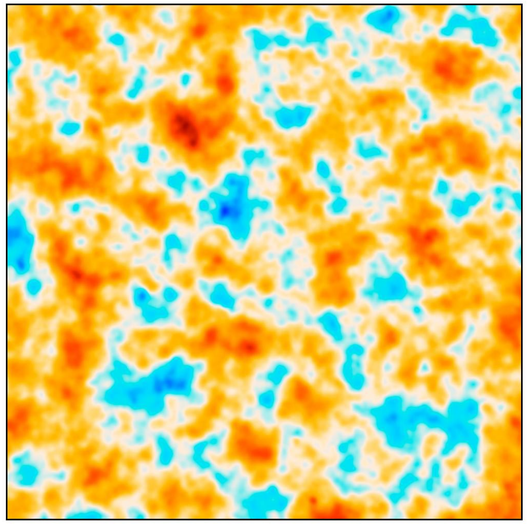
In space, no one can hear you scream









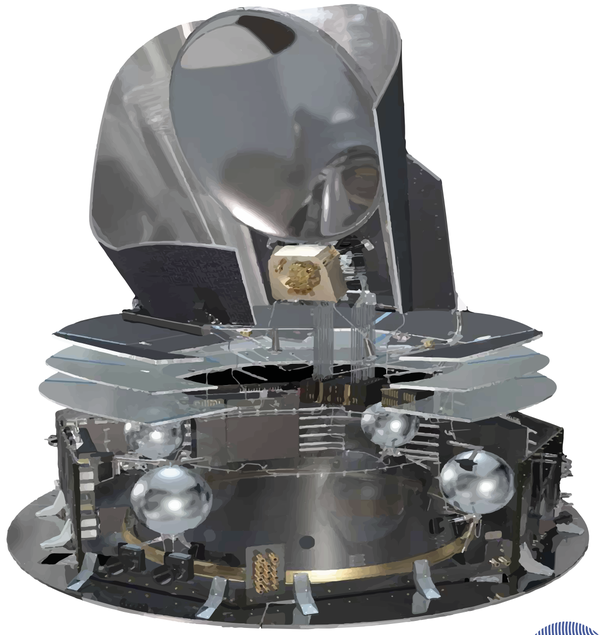


COBE 1989

WMAP 2001

Planck 2009

Planck legacy



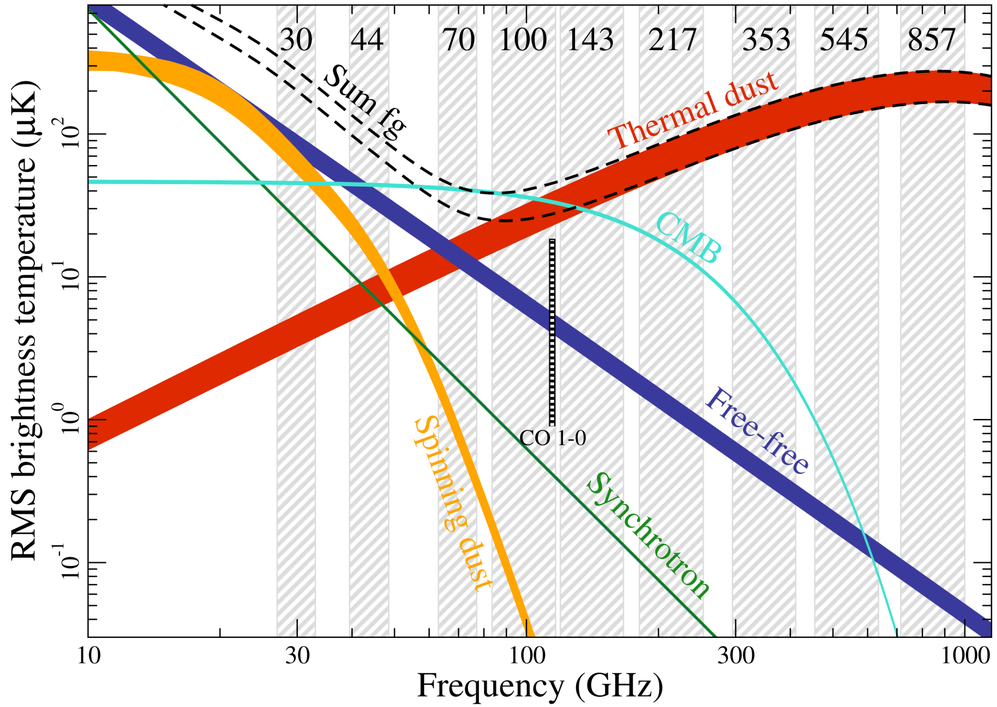
Launch : **14 May 2009**

2 instruments : HFI ( ) and LFI ( )

- Map the temperature anisotropies of CMB
- Map the polarisation of CMB
- Measure of cosmological parameters

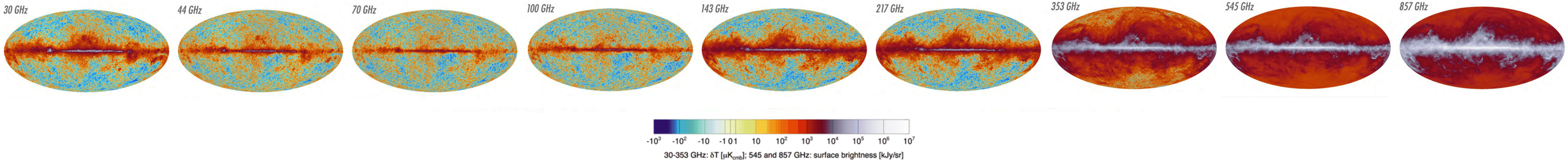
From Planck consortium

Planck legacy



Many contributions to the astrophysical signal :

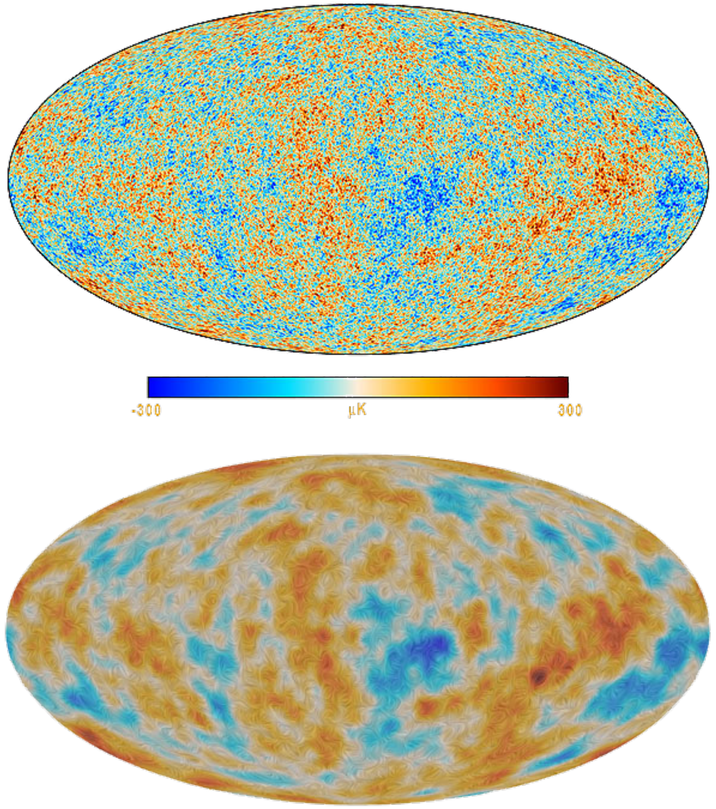
- CMB
- Galactic dust
- Synchrotron
- CO emission ray

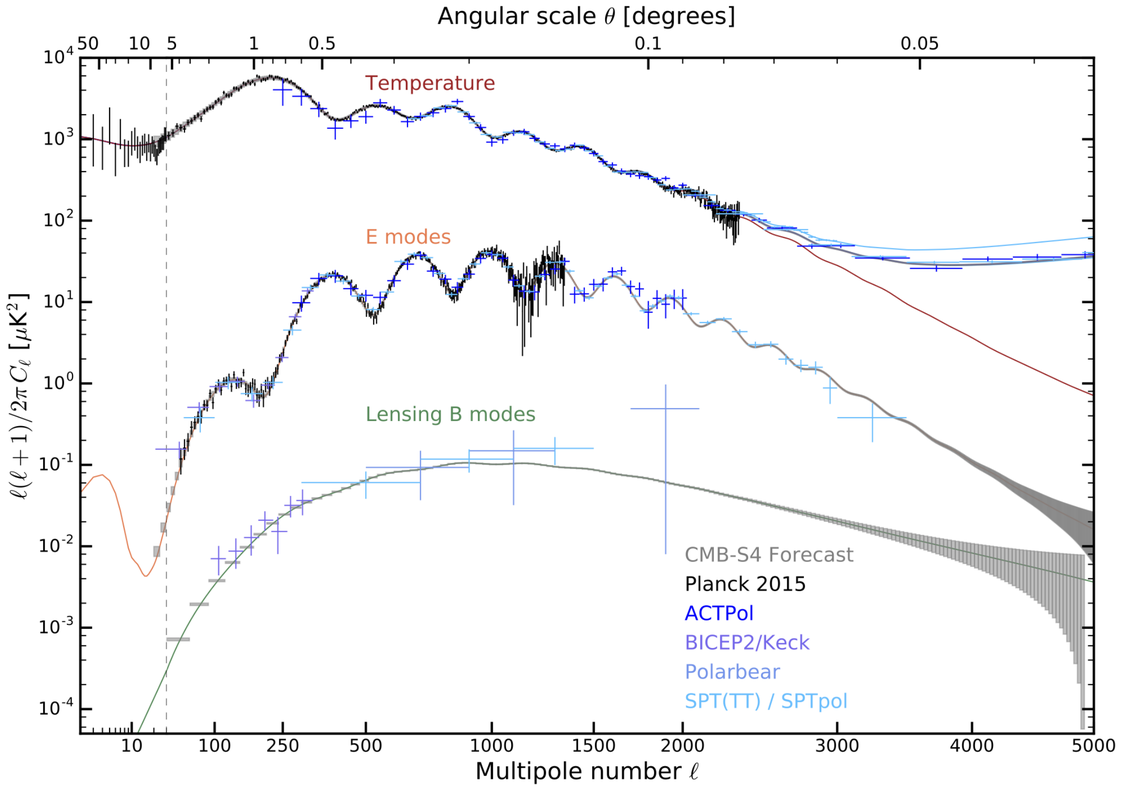


From Planck consortium

Planck legacy

CMB temperature anisotropies are between -300 μK and 300 μK around 2.726 K.
For a 5 μK sensibility, HFI detectors need to be cool down to **100 mK.**





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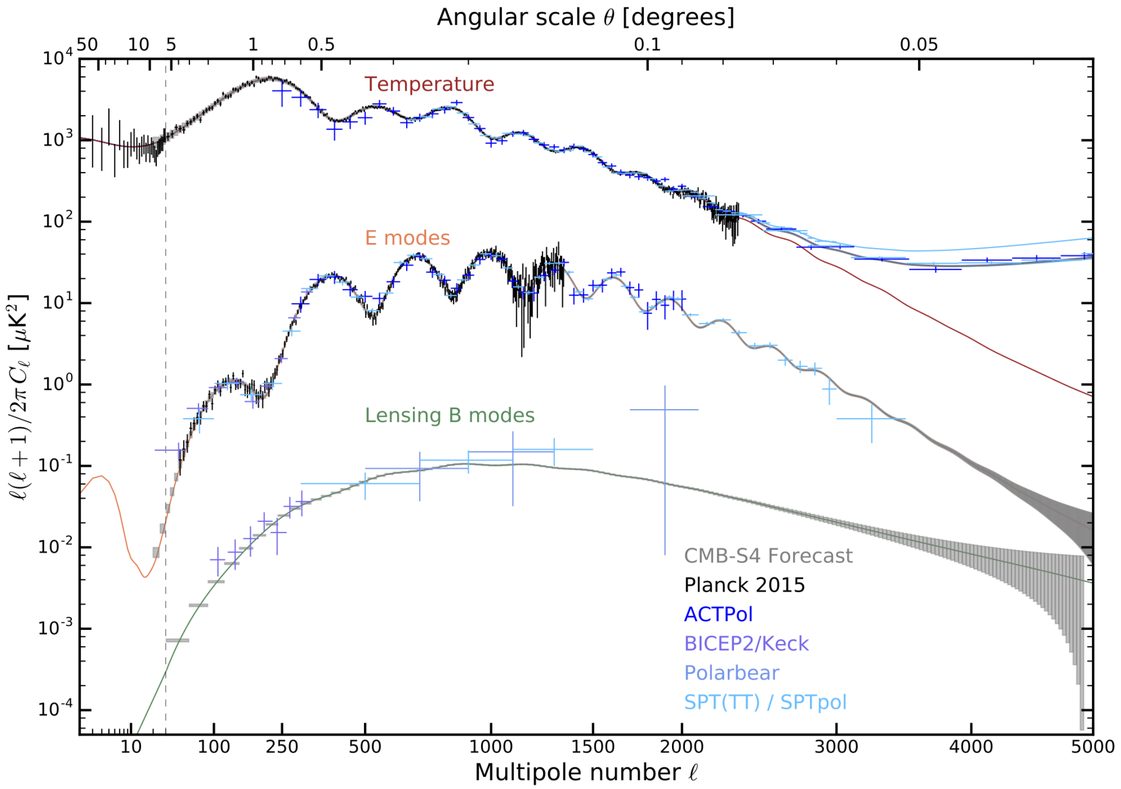


Density perturbations in the early universe → E-modes

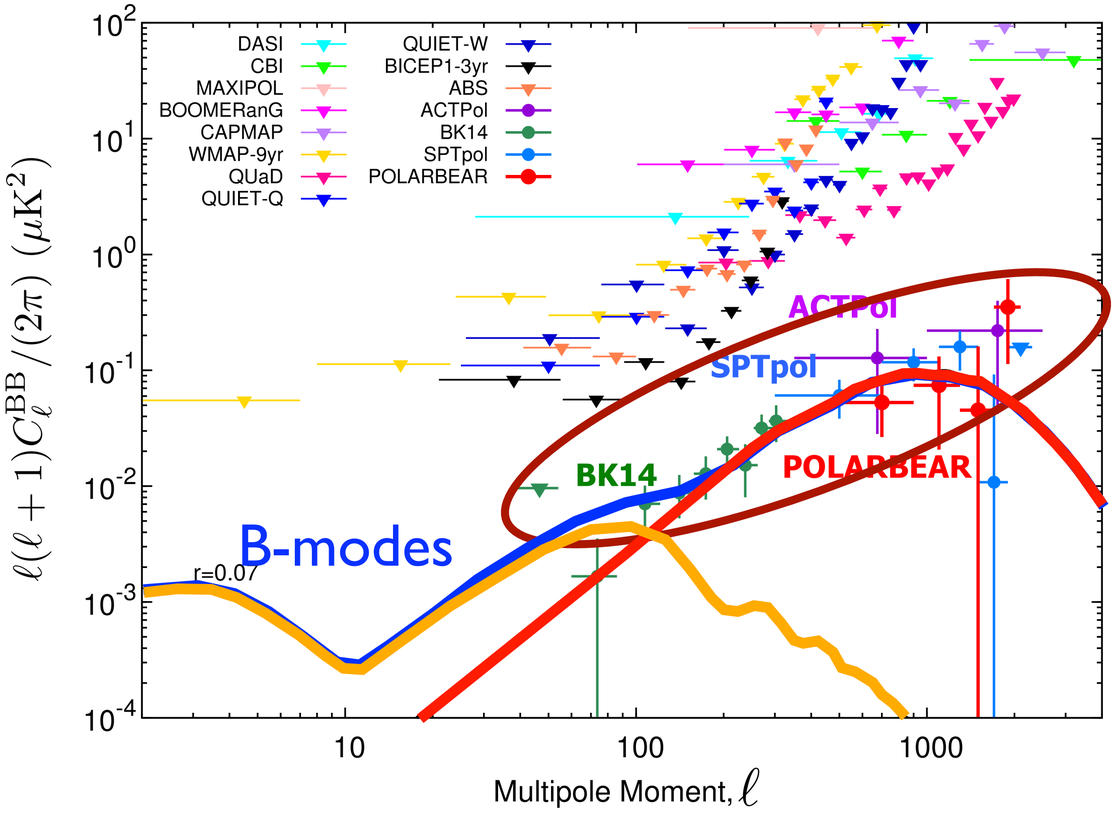
Gravitational waves from inflation → Primordial B-modes

Gravitational lensing of E-modes → Lensing B-modes

From Planck consortium

B-modes of the CMB

Curent instruments with enough sensitivity to detect secondary B-modes



Secondary B-modes

Primordial B-modes

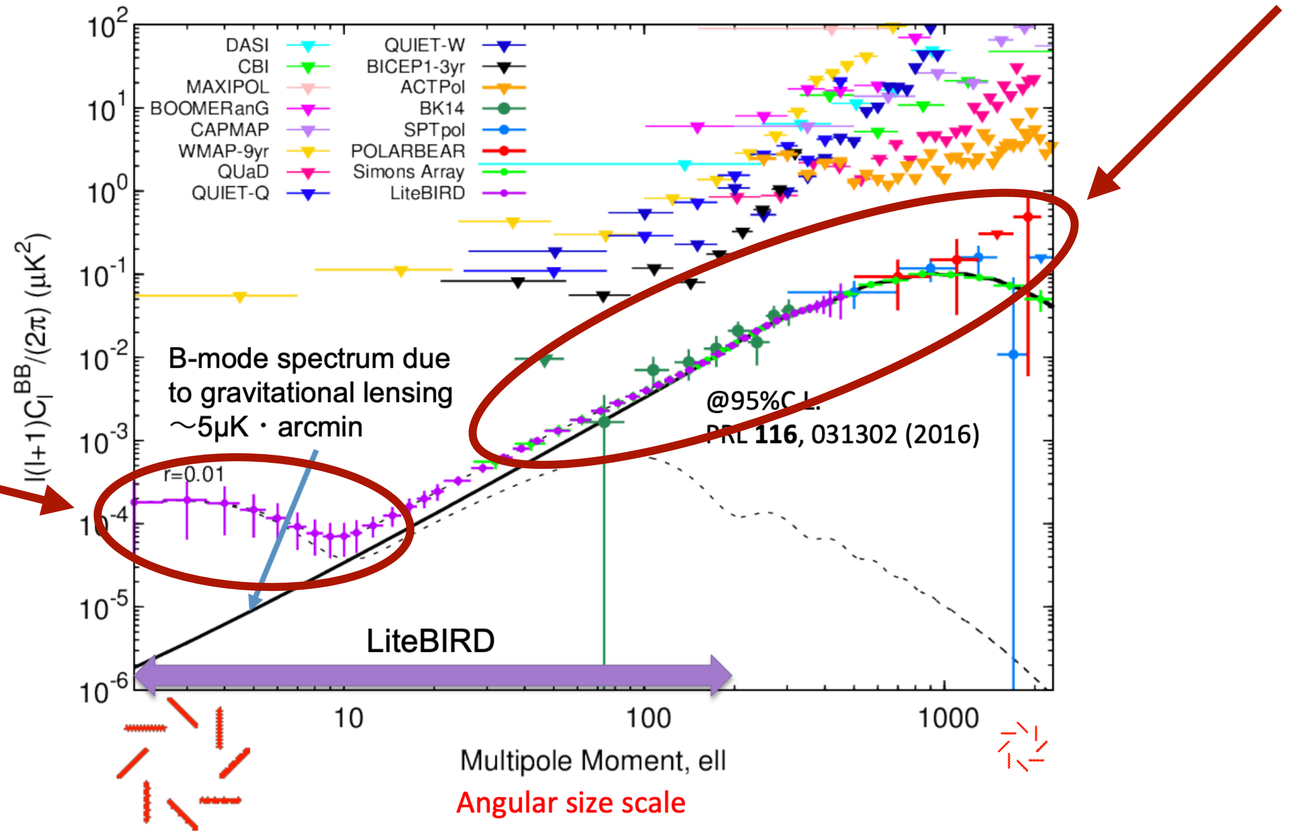
From JAXA LiteBIRD consortium

Goal : Primordial B-modes

Curent instruments with enough sensitivity to detect secondary B-modes

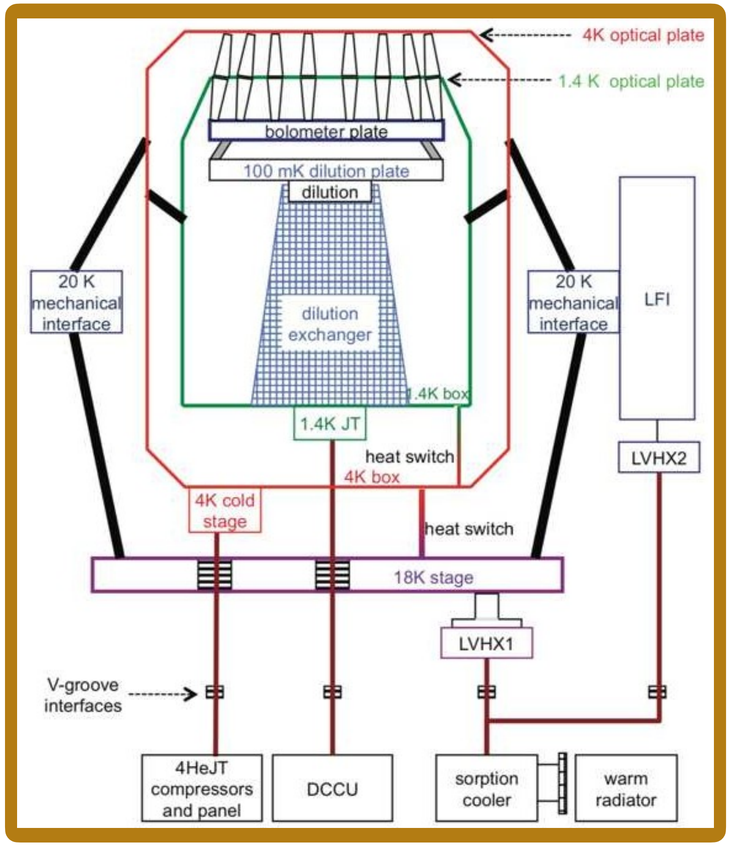
Primordial B-modes

$$\text{Sensitivity} \propto \frac{Signal}{Noise}$$



From JAXA LiteBIRD consortium

Plank HFI cryogenic system



Planck HFI cryogenic system

How to reach 100 mK?

- 50 K - Radiative Shield
- 18K - Hydrogen sorption cooler
- 4K - Joule-Thompson mechanical cooler
- 1.6K - Joule-Thompson process
- 100mK - ^{3}He/^{4}He dilution

From Planck collaboration

Open Cycle Dilution Refrigerator (OCDR) on Planck HFI

^{3}He

12000 L STP
(1 tank at 295 bars)

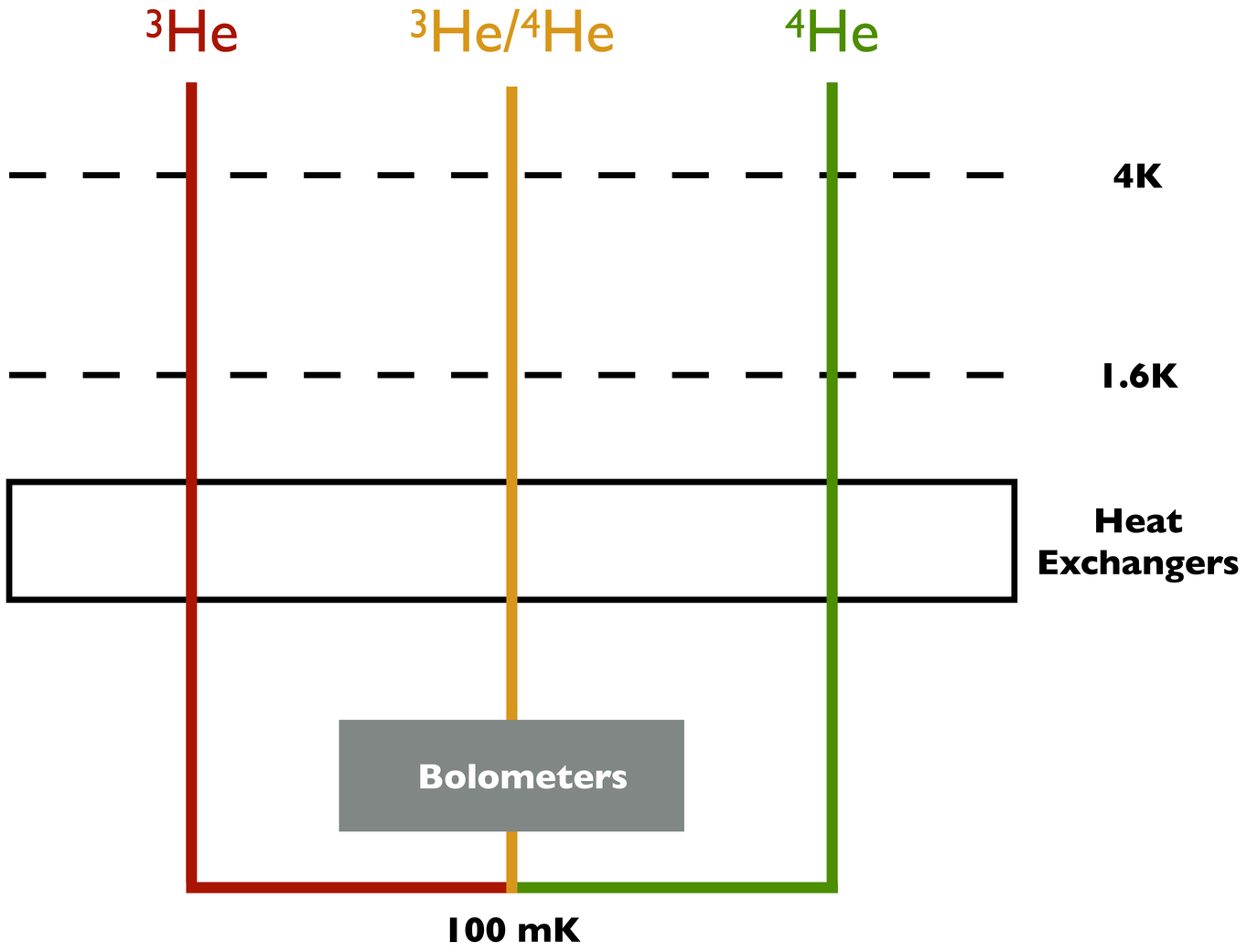
^{4}He

36000 L STP
(3 tank at 295 bars)

^{3}He/^{4}He

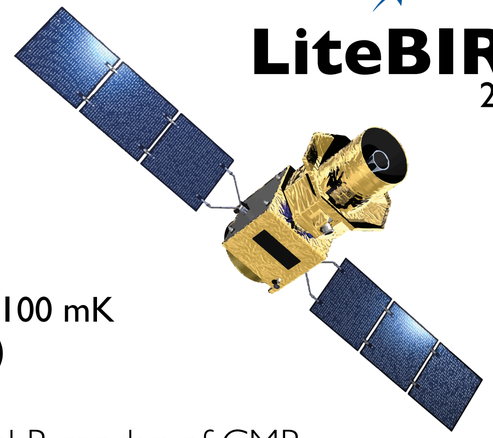
Release in space

Empty tanks = End of duty



Many missions will require such temperature

LiteBIRD
2027



100 mK

Primordial B-modes of CMB

Spica
2032

50 mK

Emission from the firsts galaxies

Athena
2031

50 mK

Hot and dense universe

Cold temperature and stability

From JAXA Website

And OCDR on the future mission Athena X-IFU ?

Planck HFI

Lifetime 2.5 years

Cooling power 0.2 µW @ 100 mK

^{3}He 12'000 L STP

^{4}He 36'000 L STP

Athena X-IFU

Lifetime 3 years

Cooling power 0.8 µW @ 50 mK

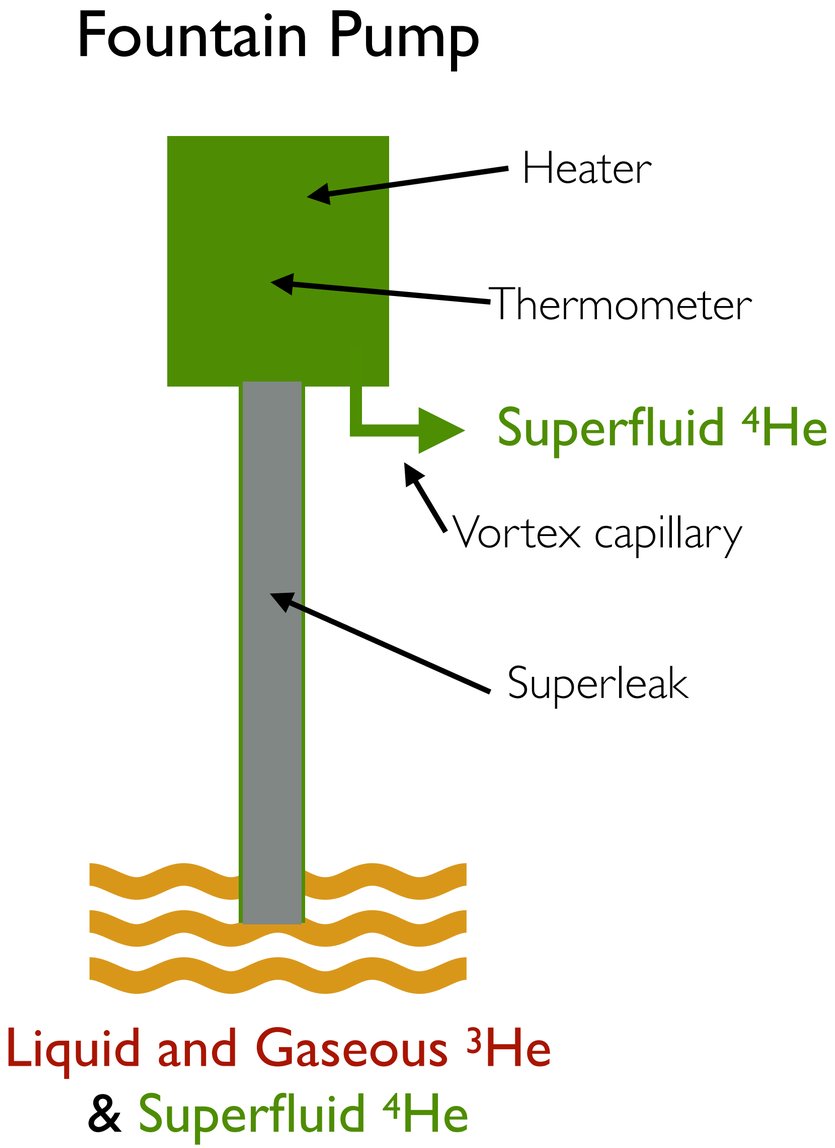
3 µW @ 100 mK

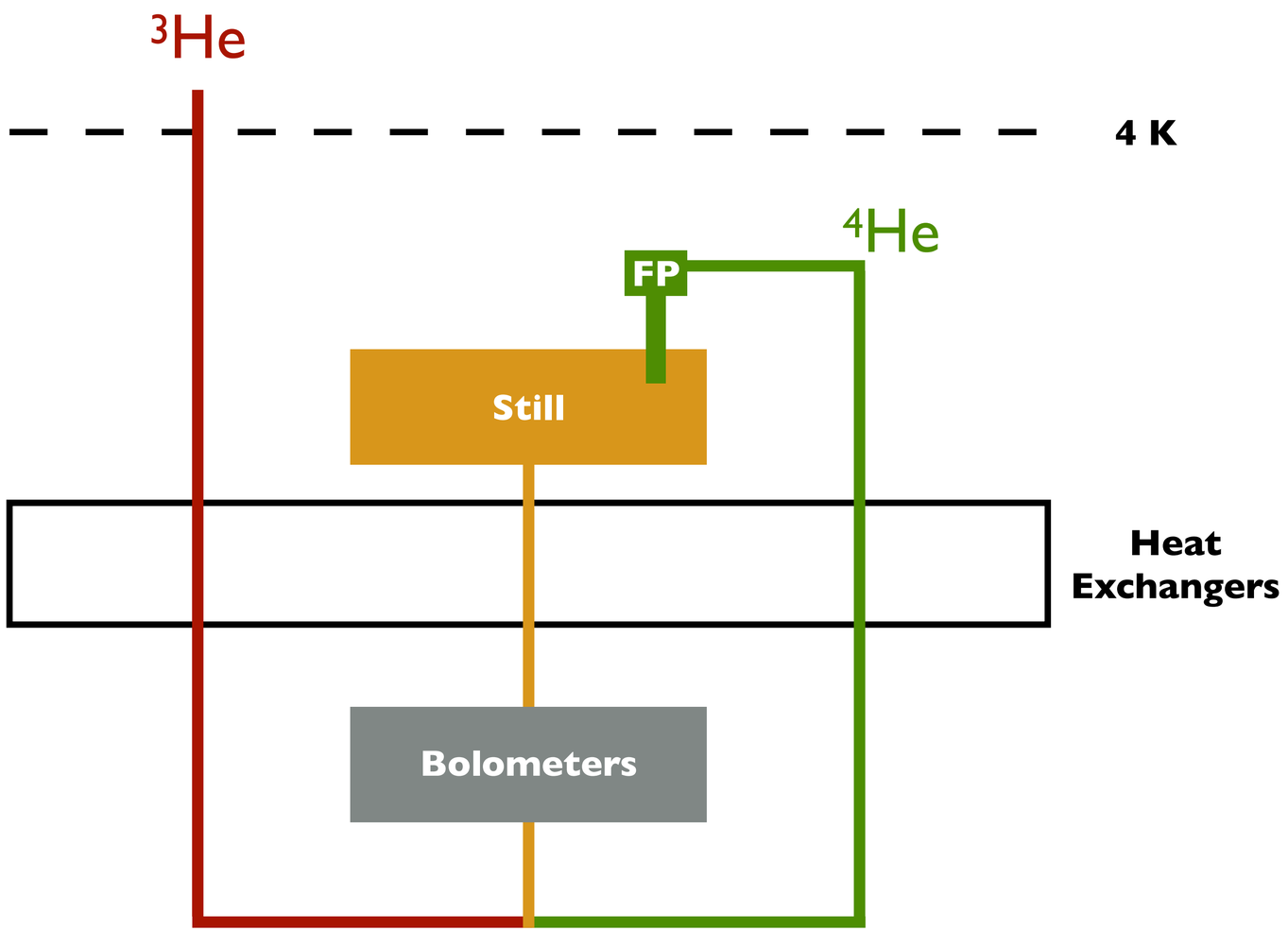
^{3}He 85'000 L STP

^{4}He 1'700'000 L STP

Too expensive

How to close the system ? Helium 4 line





How to close the system ? Helium 3 line

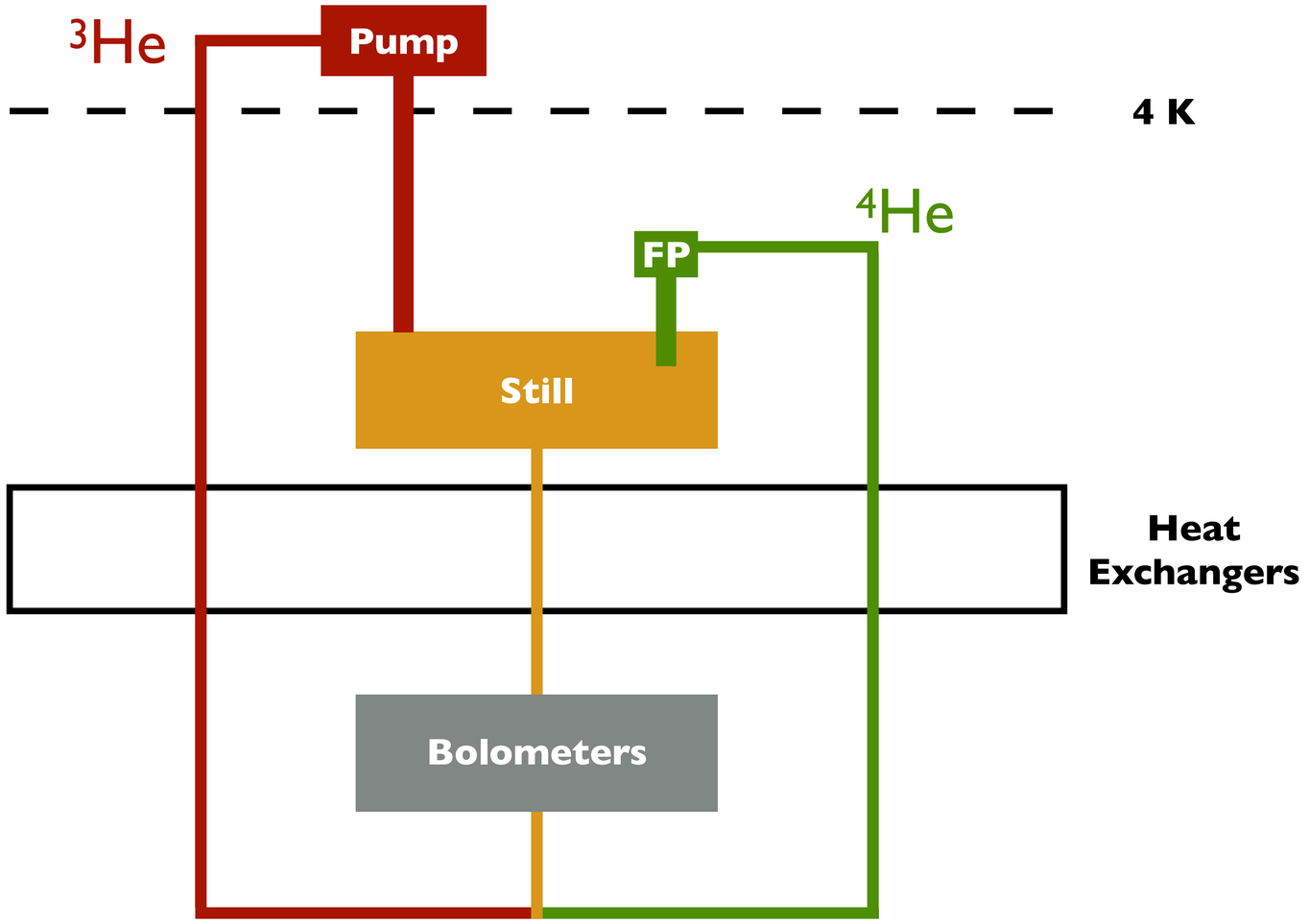
Pump on the still

↓

Lower pressure down to 15 mbar and extract ^{3}He

↓

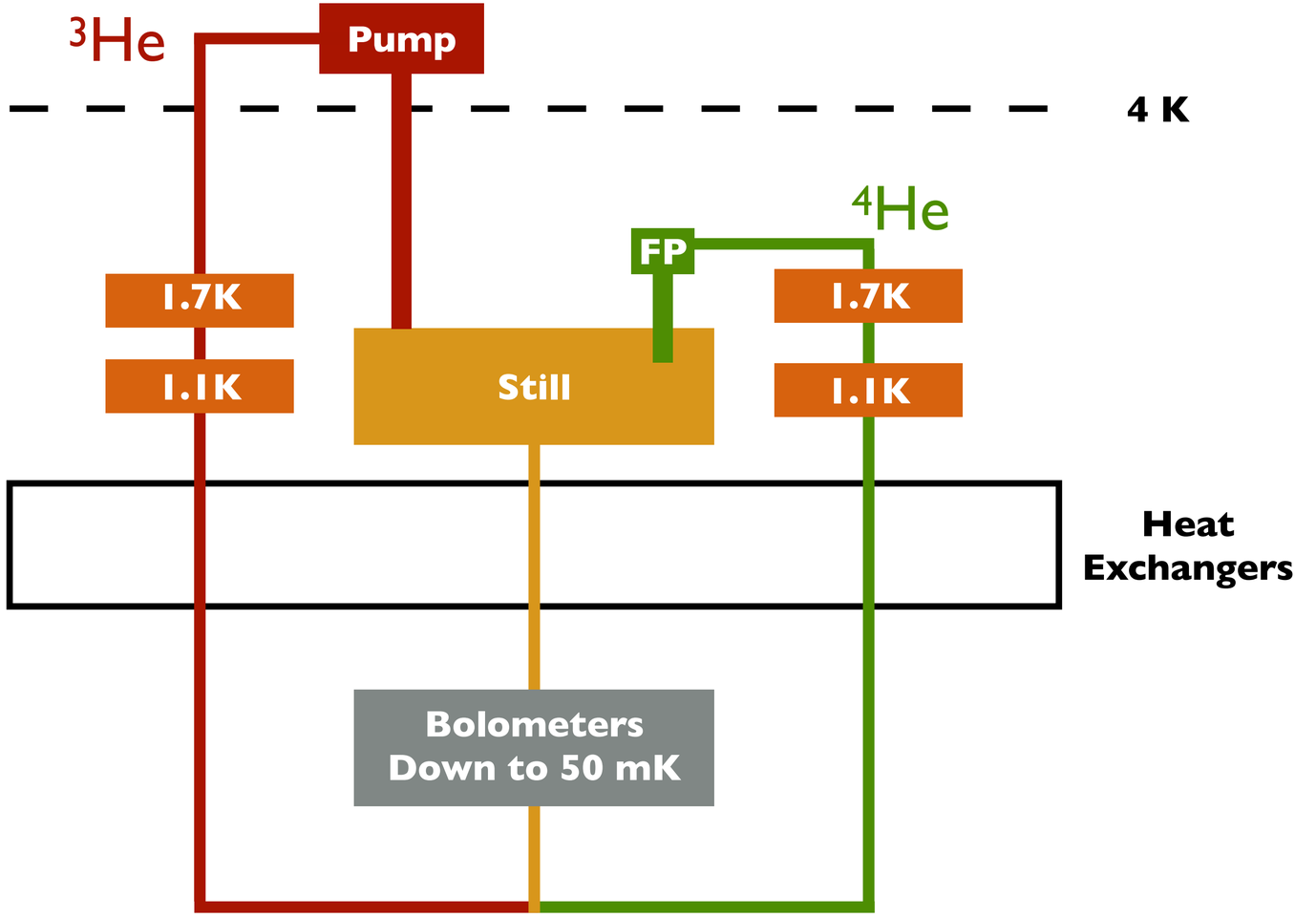
Lower temperature down to 1.1 K



The Closed-Cycle Dilution Refrigerator (CCDR)

A **Demonstrator Model (DM)** developed by *Gerard Vermeulen et al.* validate the technology at a TRL5 for temperatures down to 50 mK.

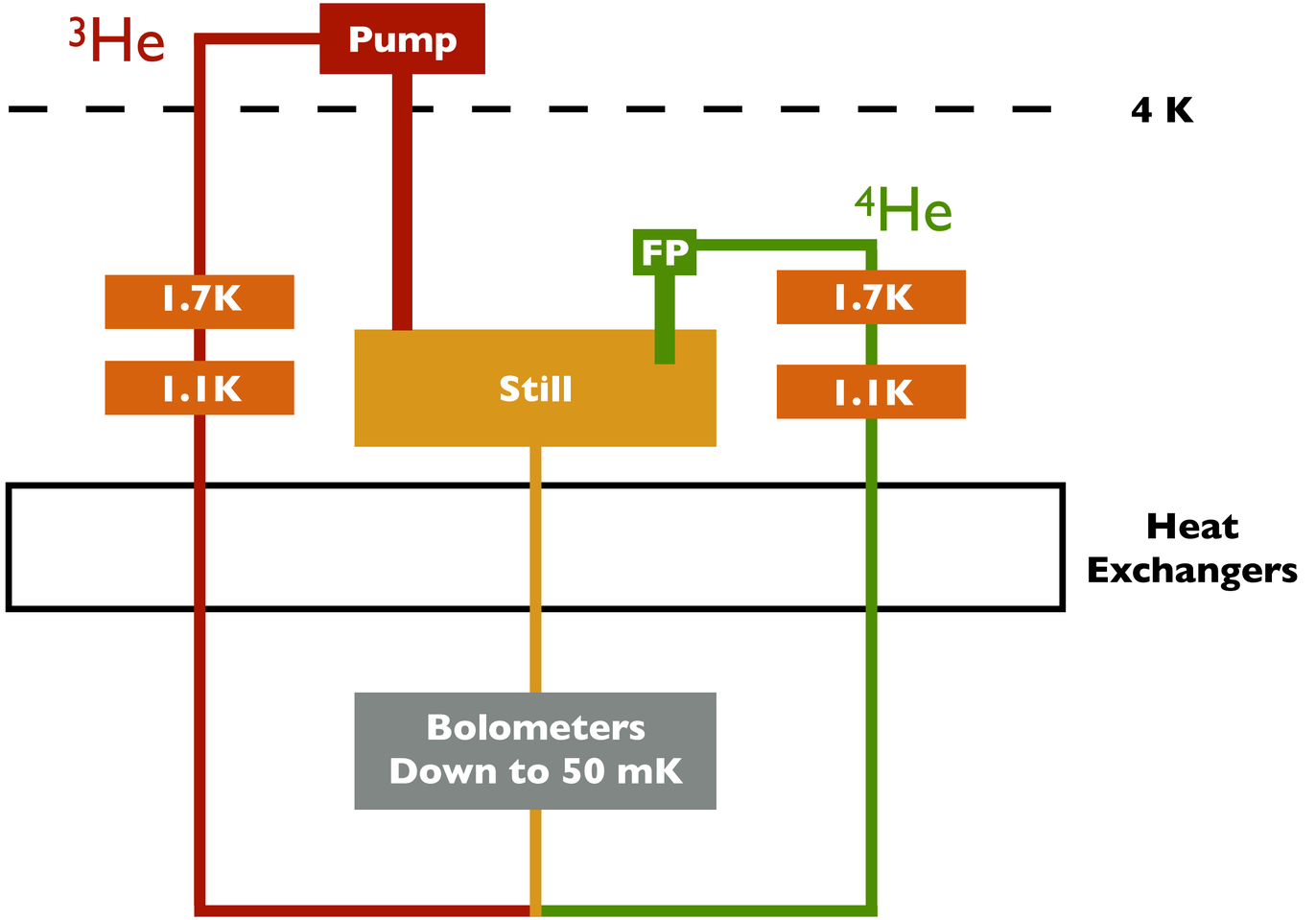
The goal is to bring this system to a TRL6 called **Engineering Model (EM)**



Some critical components

Vibrationproof

Phases separation in microgravity environment



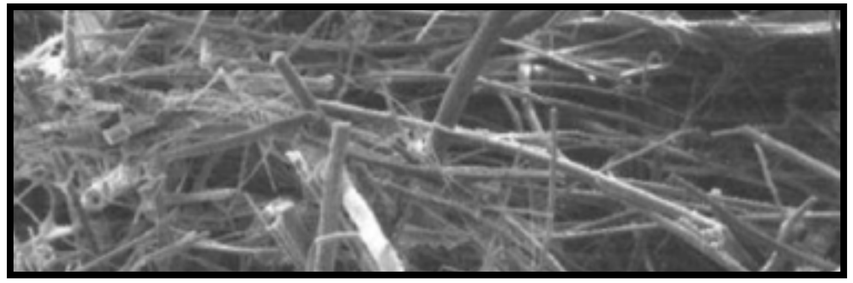
A sponge to confine the mixture

With gravity

Without gravity

Solution ?

Porous material



Separate the two isotopes on the still

Systematic effects studies

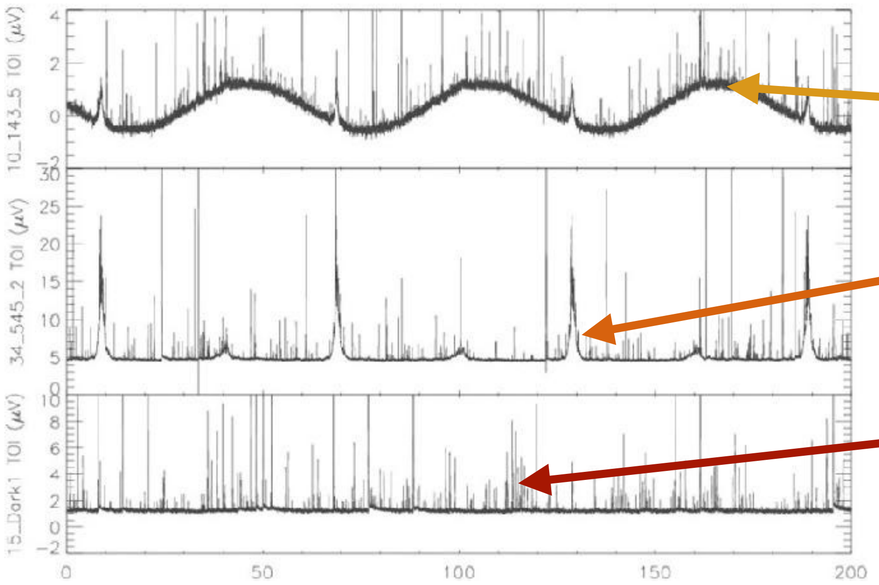
Before cleaning

After cleaning

134 GHz

545 GHz

Blind

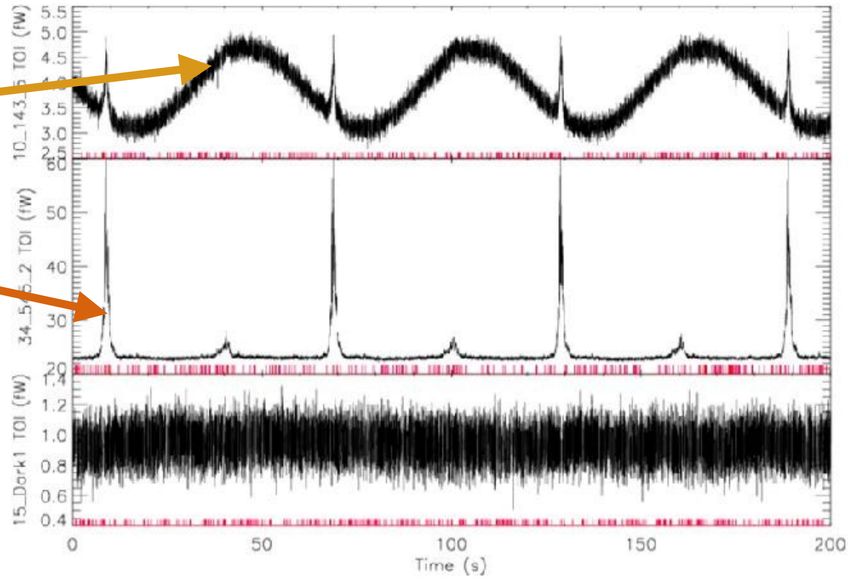


From Planck Collaboration

Dipole

Galaxy

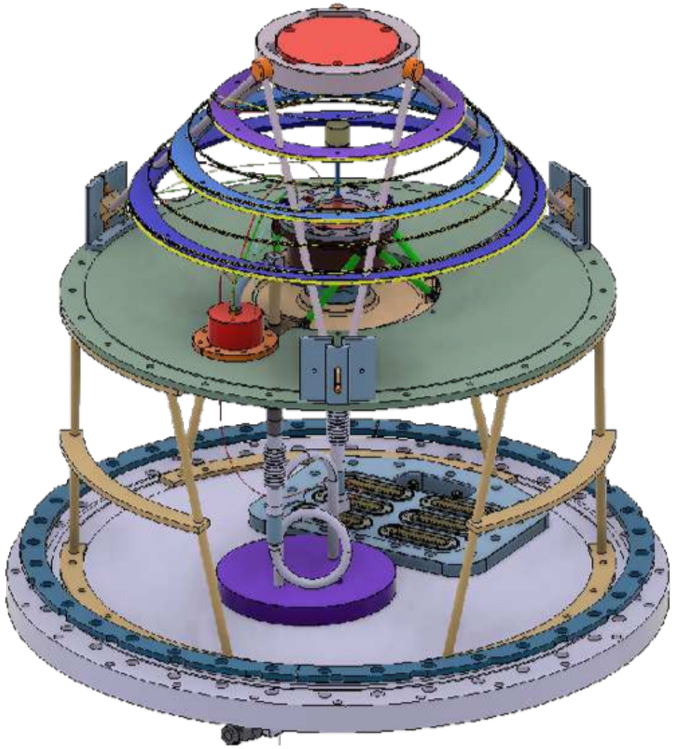
Cosmics



From Planck Collaboration

Develop a physical model of the CCDR

And later ?

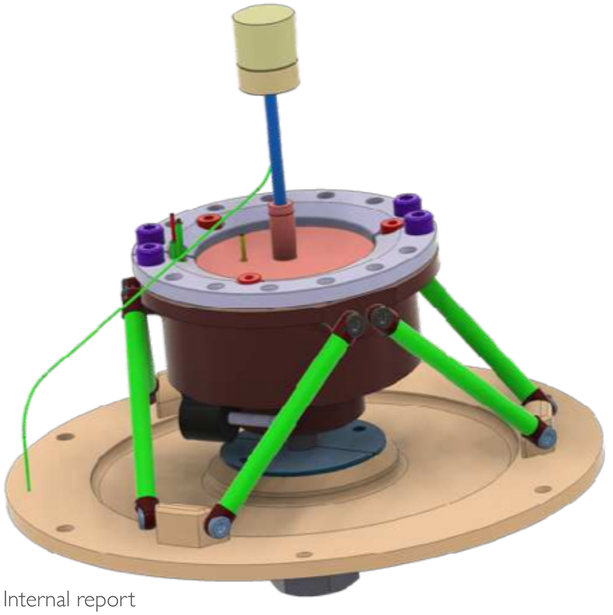


Internal report

Experiment

Model

Simulations



Internal report

Elbereth 2021

Thanks for your attention

Valentin SAUVAGE