

Preventivi 2020

LITEBIRD

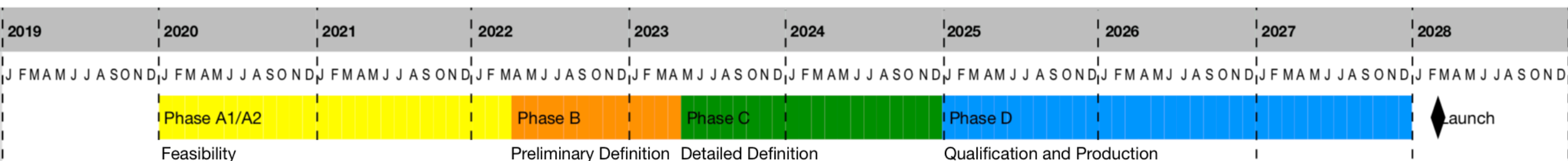


Giovanni Signorelli
INFN Sezione di Pisa

CdS 4 Luglio 2019

Perchè LiteBIRD ora

- Richiesta di apertura di una **nuova sigla di CSN2** per formalizzare la **partecipazione INFN** all'esperimento **LiteBIRD**
 - Partecipazione a livello “personale” da diversi anni finanziata da ASI/COSMOS
 - Identificati chiari contributi rilevanti dal punto di vista HW
- **LiteBIRD** è la prosecuzione naturale della fisica di **LSPE**
 - Esperienza creata in sezione e a livello nazionale sul **readout di rivelatori criogenici TES**
 - Esperienza esistente in sezione nella realizzazione di front-end (**meccanica-elettronica**) per esperimenti nello **spazio**
 - Sinergia a “feedback positivo”
- È il **momento giusto**
 - LiteBIRD è stata **appena approvata** (Maggio 2019) da JAXA come **unica** Large-mission candidata per un **lancio nel 2028**
 - Official announcement
 - http://www.isas.jaxa.jp/home/rikou/godo/2019/0602/gbi7uzhxfxmz/misison_selection_announcement_may2019.pdf
 - Passaggio da pre-fase A a **fase-A** (design and feasibility) in cui si ridiscutono **responsabilità** e **competenze**



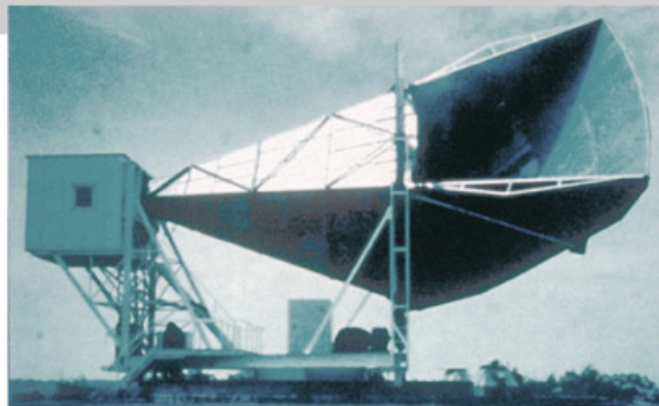
Piano della presentazione

- Breve richiamo alla fisica della polarizzazione della radiazione cosmica di fondo
- Lo strumento
- Panorama sul contributo italiano in generale
- Il contributo INFN
- Richieste finanziarie e di personale.

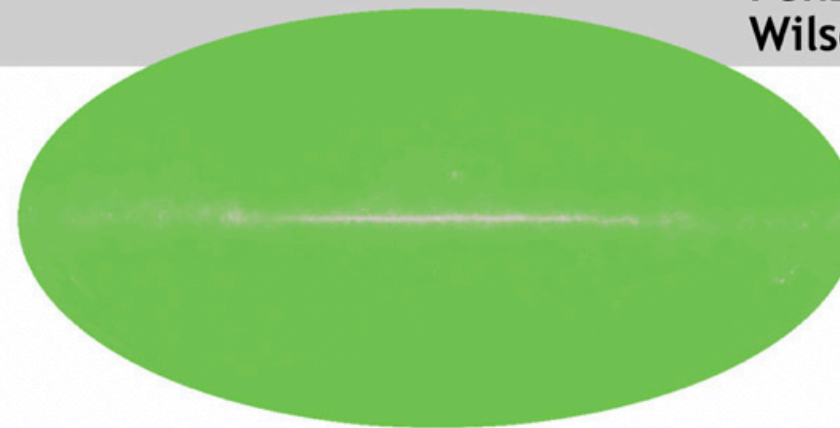
LiteBIRD science

$O(1)$

1965



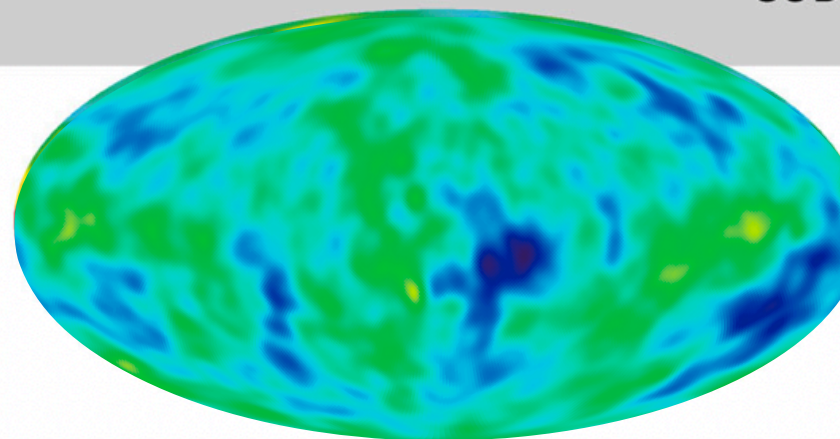
Penzias and
Wilson



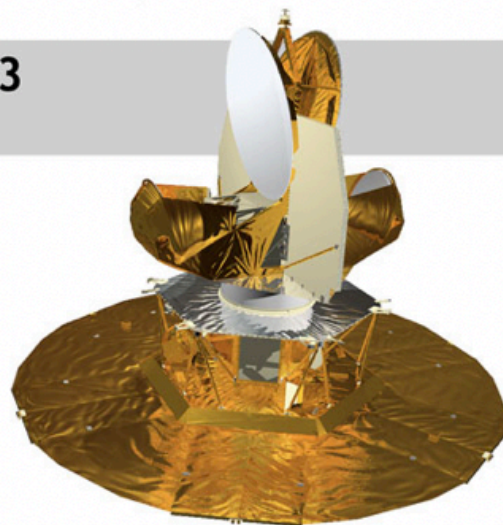
1992



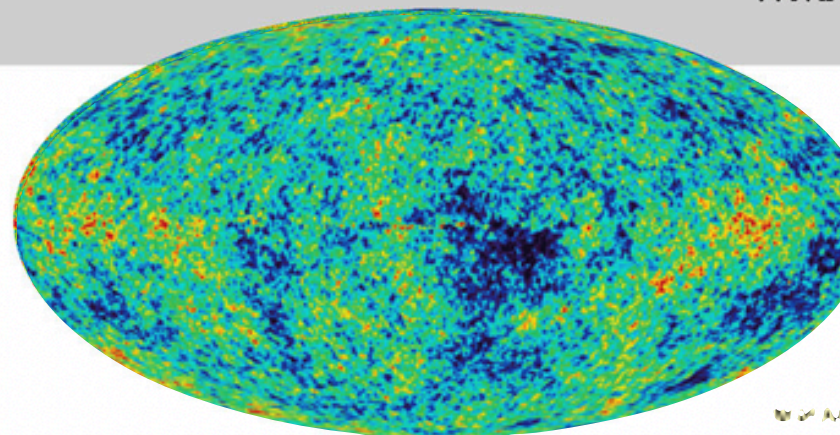
COBE



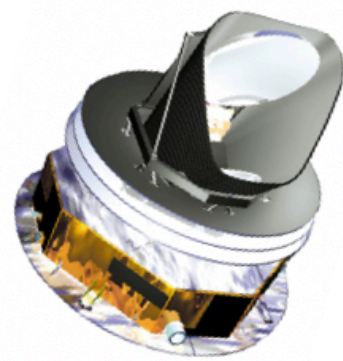
2003



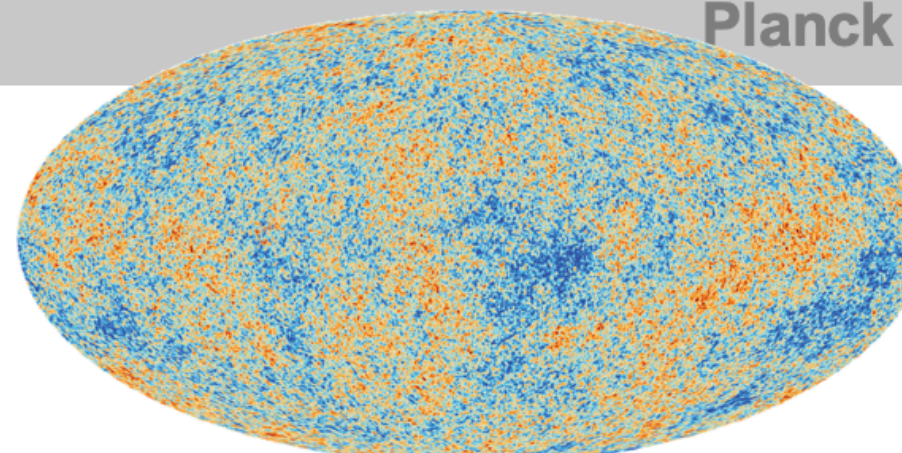
WMAP



2009 2018



Planck



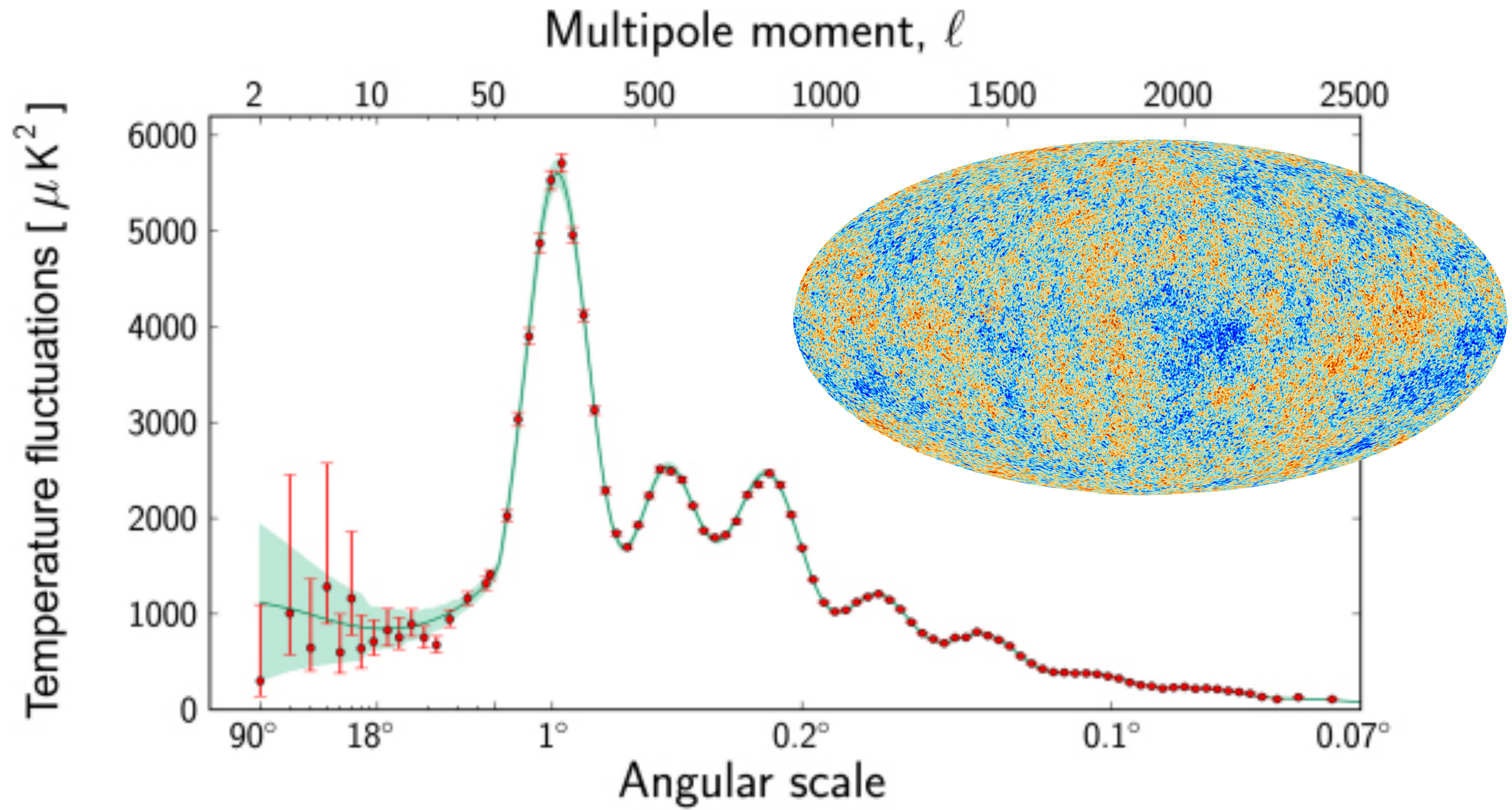
Risoluzione spaziale



$O(10^{-4})$

Planck fit a 6 parametri

- **dimensione dell'universo** connesso all'istante del **decoupling** nella scala attuale ($\rightarrow$ universo è piatto)
- quantità di **materia** (barioni/radiazione) al momento del decoupling
- parti dell'universo **correlate** su scale maggiori di quelle causali (ct0)



cosmic horizon - the big bang

cosmic background radiation

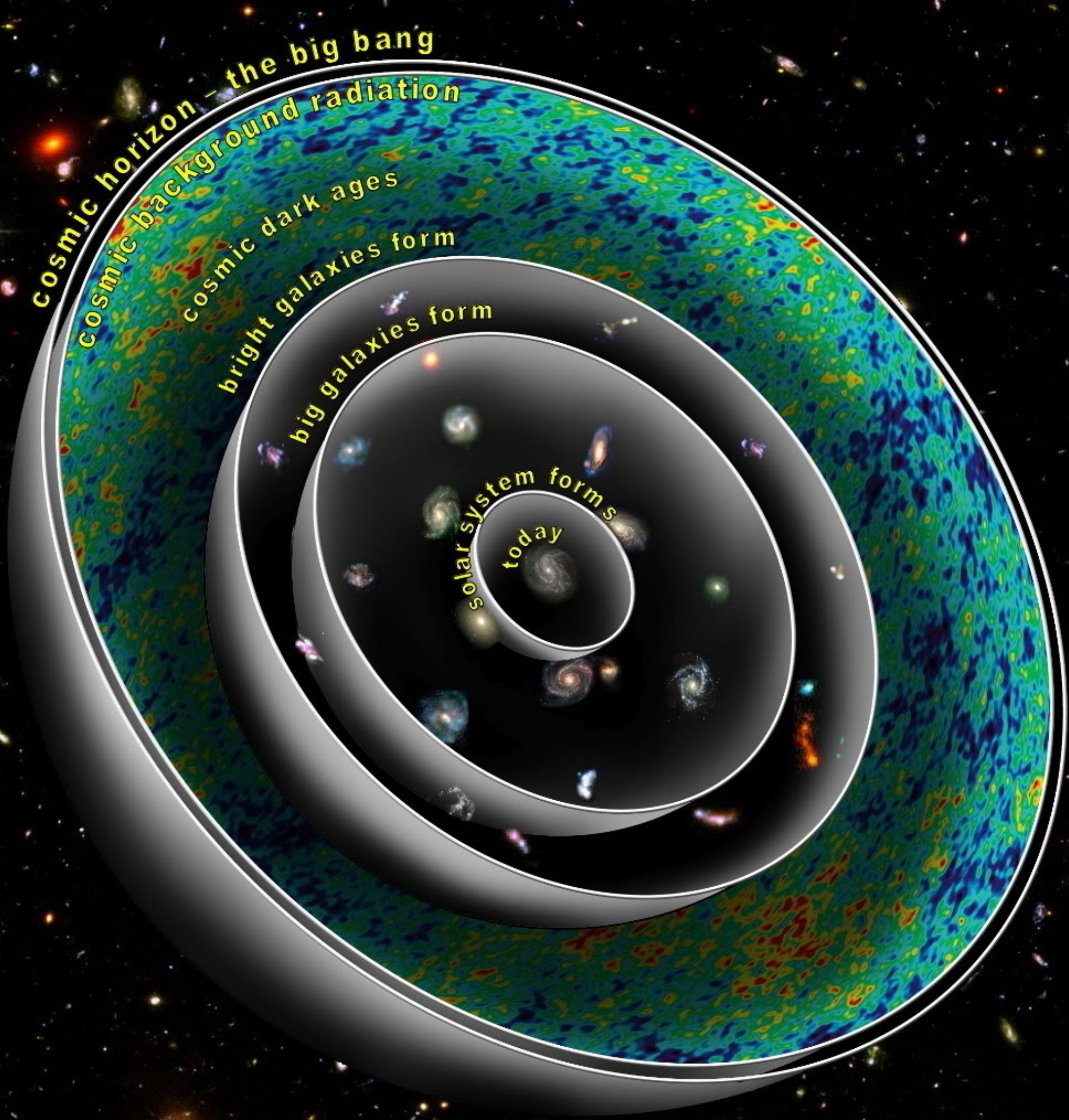
cosmic dark ages

bright galaxies form

big galaxies form

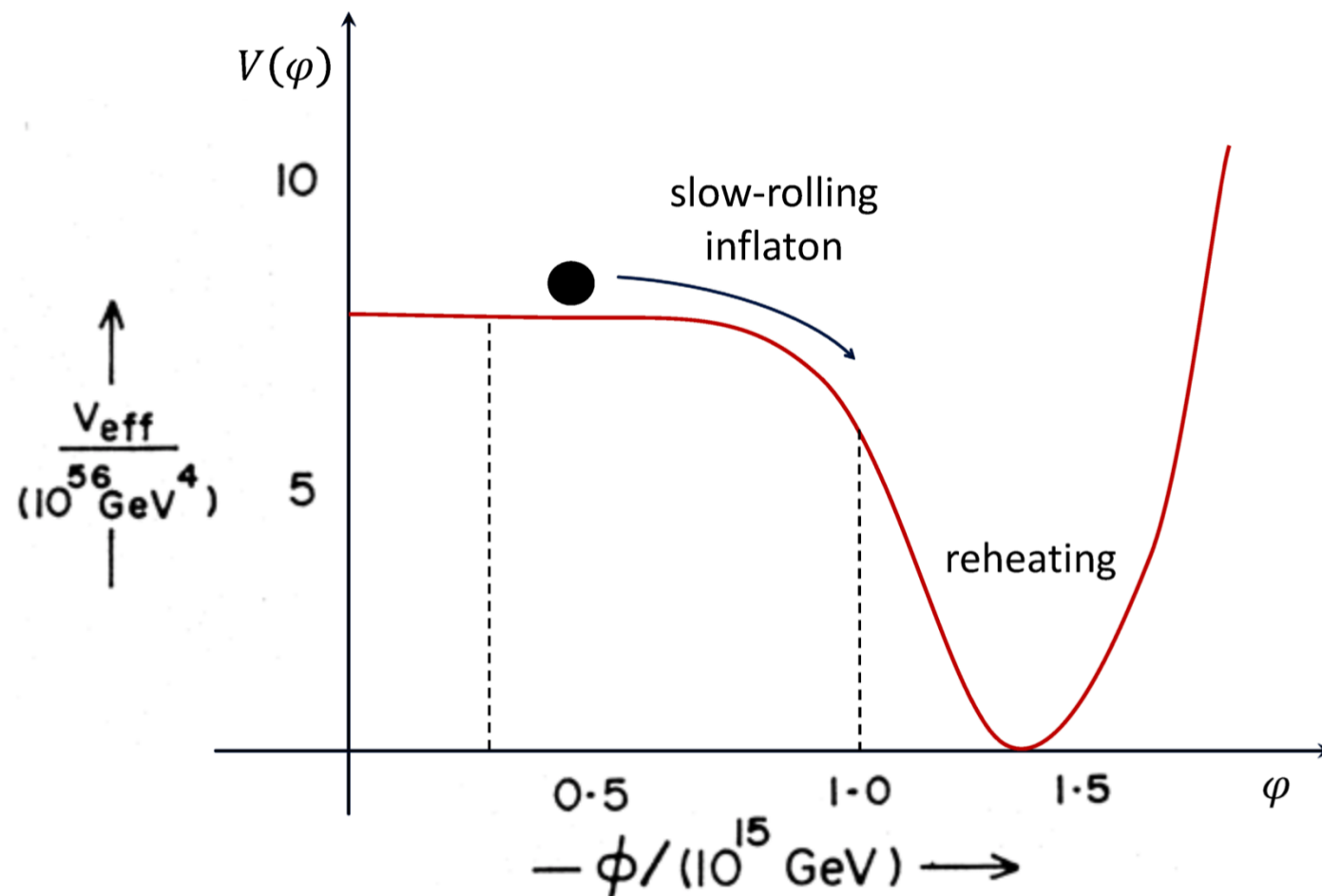
solar system forms

today



Cos'è l'inflazione

- L'energia dell'universo primordiale è dominata dal potenziale dell'inflatone
- L'inflatone, originariamente in un minimo locale del potenziale, rotola lentamente verso il vero minimo



$$\mathcal{H} = \left(\frac{\dot{a}}{a} \right) = \text{cost} \quad a(t) = a_e e^{\mathcal{H}(t-t_e)} \quad \text{fattore } 2^{60}$$

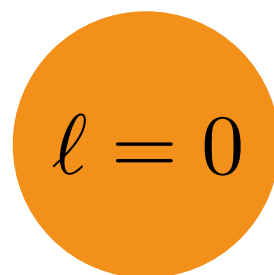
- Dilatazione dello spazio, in particolare della metrica
- Fluttuazioni quantistiche $\Rightarrow$ origine delle anisotropie

- La **metrica** viene “**dilatata**”
- Le **fluttuazioni della metrica** vengono espanse di un **fattore** $2^{60} \sim 10^{18}$

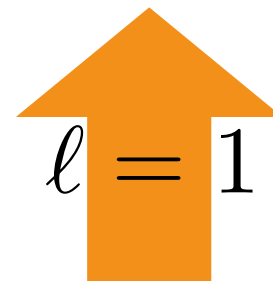
$$g_{\mu\nu} = \left(4 \times 4 \right) \rightarrow 3 \times 3$$

$$M_{ij} = \begin{pmatrix} * & * & * \\ * & * & * \\ * & * & * \end{pmatrix} = \lambda \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + \begin{pmatrix} 0 & x & y \\ -x & 0 & z \\ -y & -z & 0 \end{pmatrix} + \begin{pmatrix} a & b & c \\ b & d & e \\ c & e & -a-d \end{pmatrix}$$

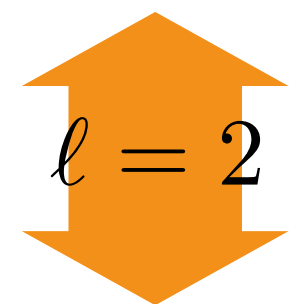
9
=
1
+
3
+
5



scalari



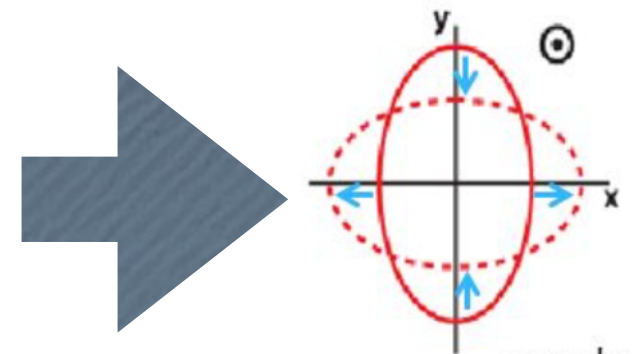
vettoriali



tensoriali

- Fluttuazioni

- **Onde Gravitazionali Primordiali!**



Affermazioni

Studiando la polarizzazione della CMB
possiamo risalire ai primi istanti
di vita dell'universo (10^{-35} sec)

Possiamo risalire alla scala di energia
dell'inflazione che è correlata alla scala di energia
di Grande Unificazione ($10^{15\div 16}$ GeV)

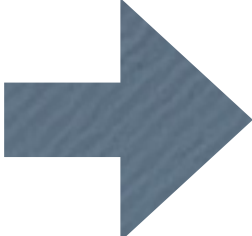
scalar perturbation spectrum

$$\Delta_{\mathcal{R}}^2(k) \equiv \frac{k^3}{2\pi^2} \langle |\mathcal{R}|^2 \rangle = \frac{1}{8\pi^2} \frac{H^2}{M_{\text{Pl}}^2 \epsilon}$$

tensor perturbation spectrum

$$\Delta_h^2(k) \equiv 2 \frac{k^3}{2\pi^2} \langle |h_{p,k}|^2 \rangle = \frac{2}{\pi^2} \frac{H^2}{M_{\text{Pl}}^2}$$

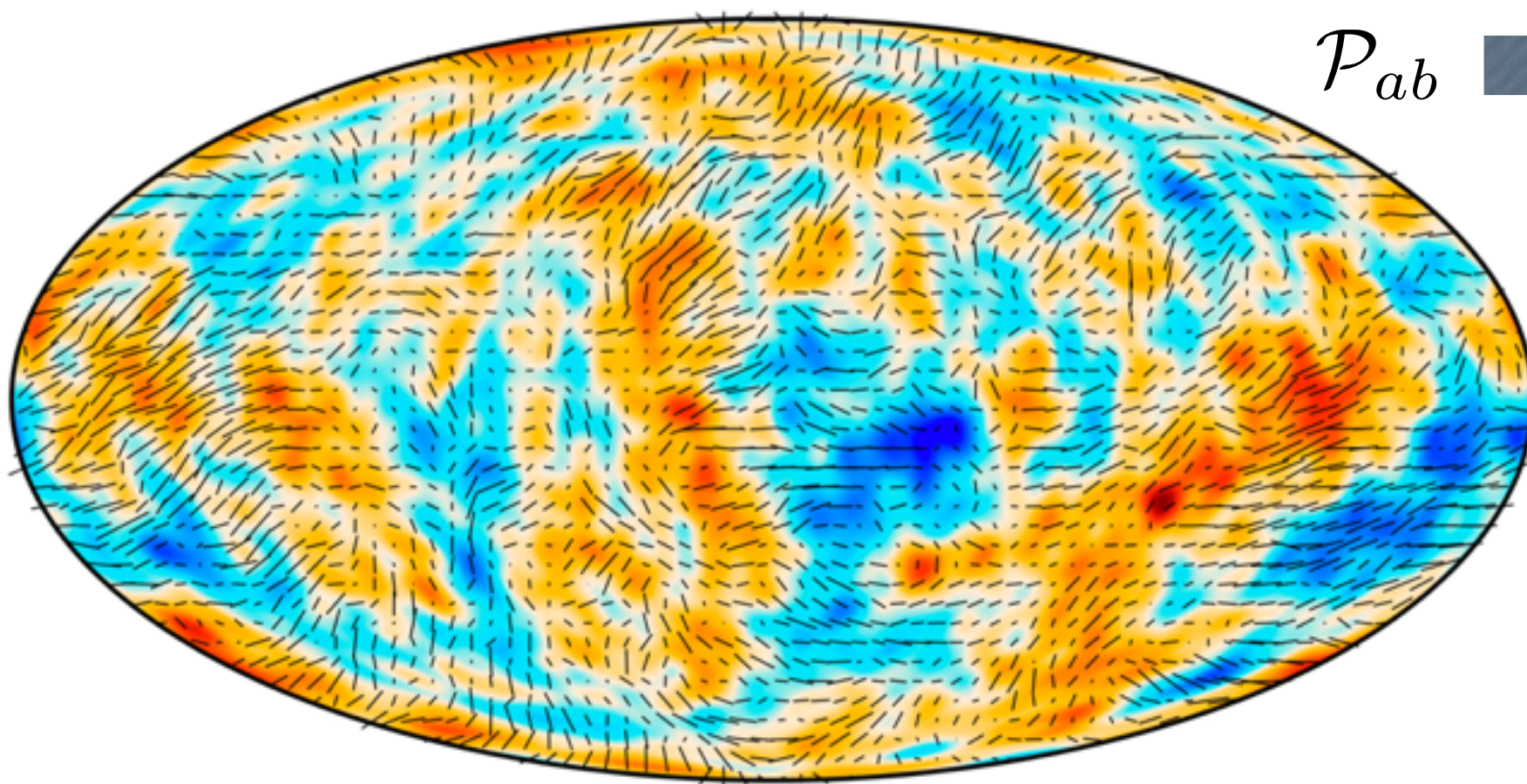
tensor-to scalar ratio related to inflation potential scale


$$r \equiv \frac{\Delta_h^2}{\Delta_{\mathcal{R}}^2} = 16\epsilon \simeq 0.1 \left[\frac{V}{(2 \times 10^{16} \text{ GeV})^4} \right]$$

$$\epsilon = 3 \frac{\dot{\phi}^2/2}{V + \dot{\phi}^2/2} \simeq \frac{M_{\text{Pl}}^2}{2} \left(\frac{V'}{V} \right)^2$$

Come la misuro?

- **Monopole** term: 2.725 K blackbody $O(1)$
- **Dipole** term: 3.355 mK $O(10^{-3})$
- **Anisotropy**: 100 μK rms $O(10^{-4})$
- **Tensor perturbations** produce a background of **primordial gravitational waves**
 - **E-mode polarization**: 3 μK rms $O(10^{-6 \div 7})$
 - **B-mode polarization**: <500 nK rms



1 0.41 μK

-160

160 μK

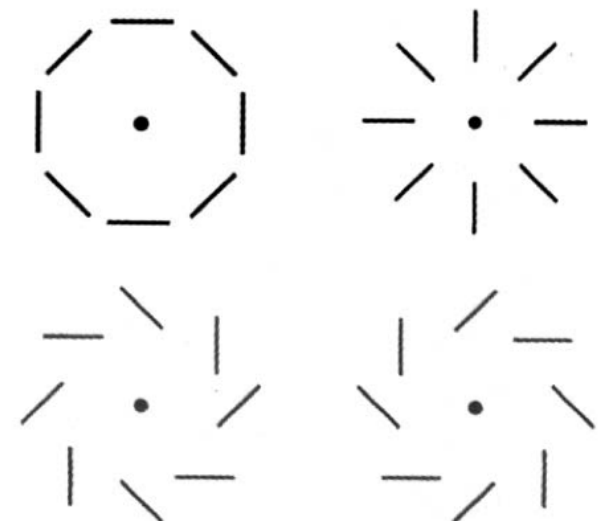
$\mathcal{P}_{ab}$



$$E \sim \partial_a \partial_b \mathcal{P}_{ab}$$

$$B \sim \epsilon_{ac} \partial_b \partial_c \mathcal{P}_{bc}$$

E-modes



B-modes

Come la misuro?

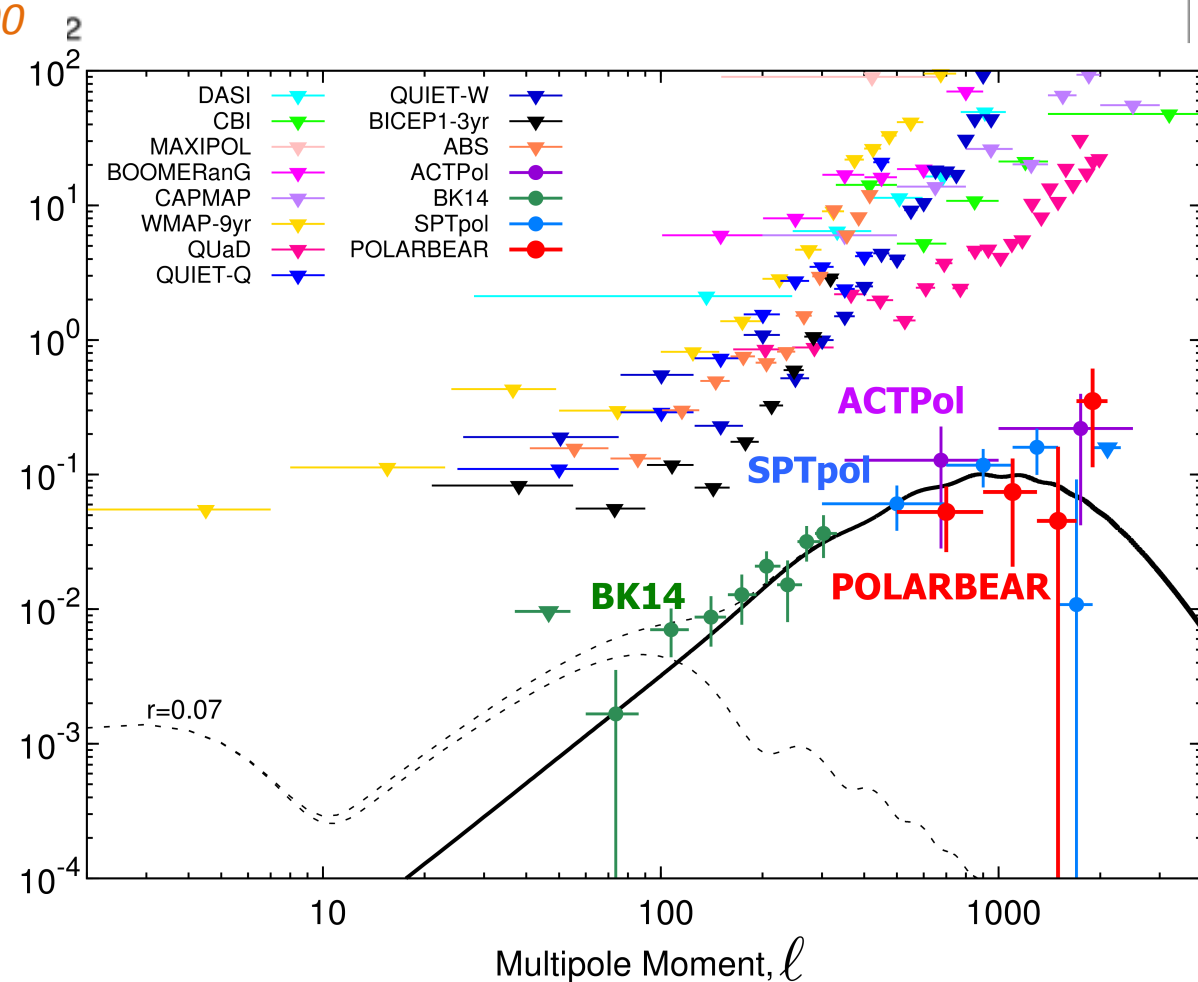
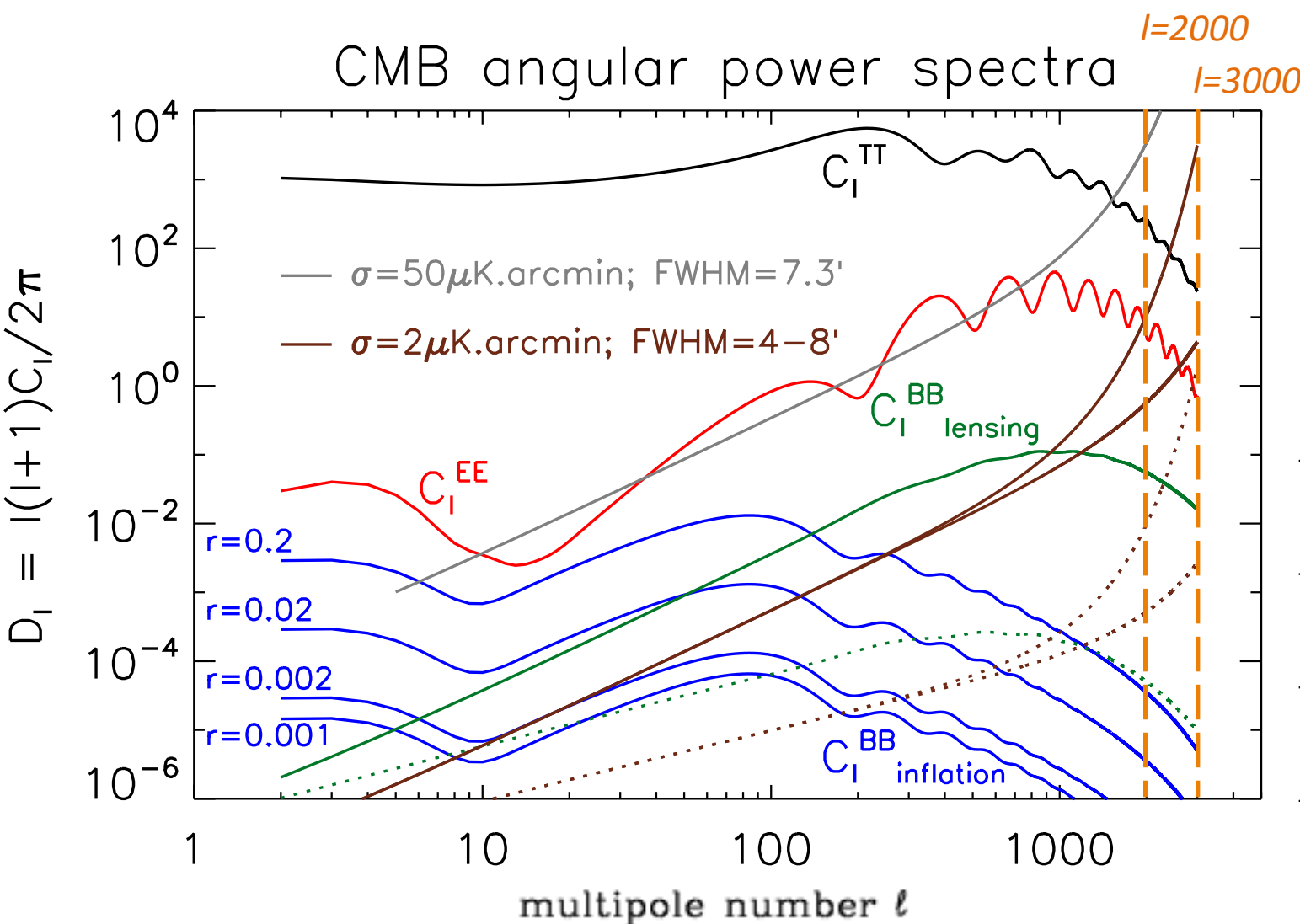
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$O(1)$

$O(10^{-3})$

$O(10^{-4})$

$O(10^{-6 \div 7})$

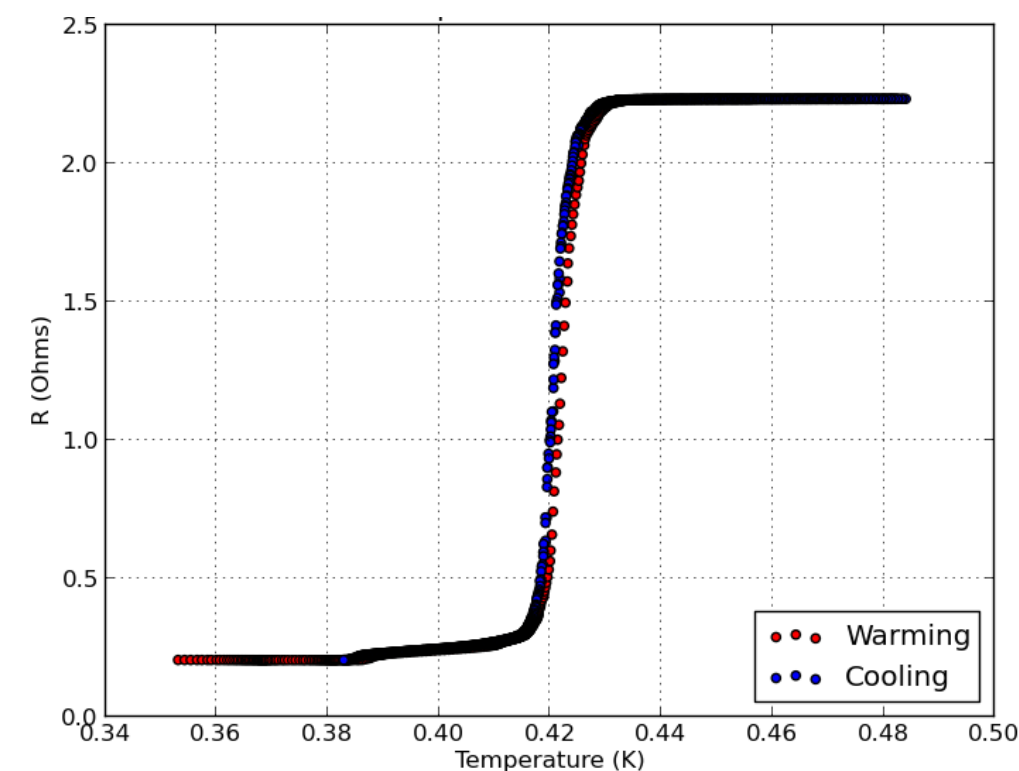


Transition-Edge Sensors

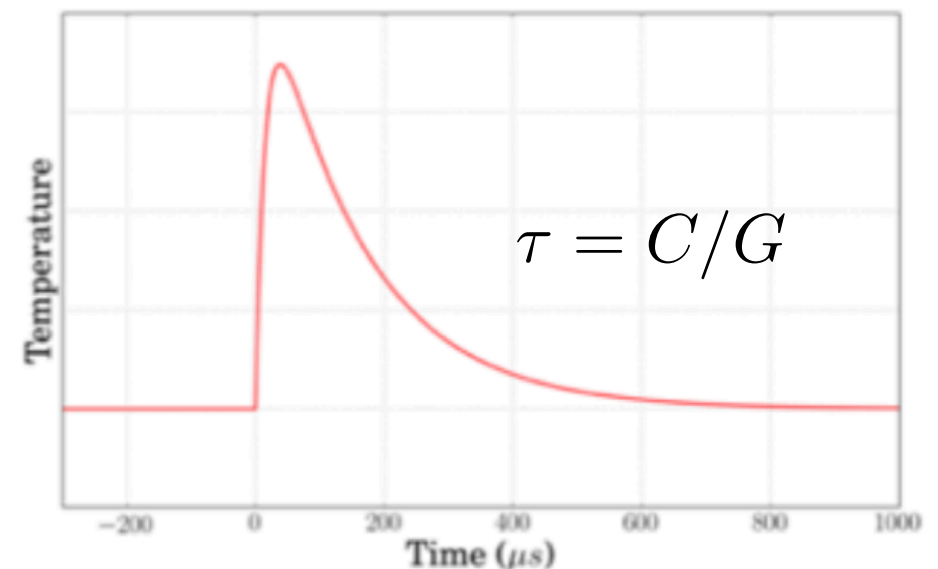
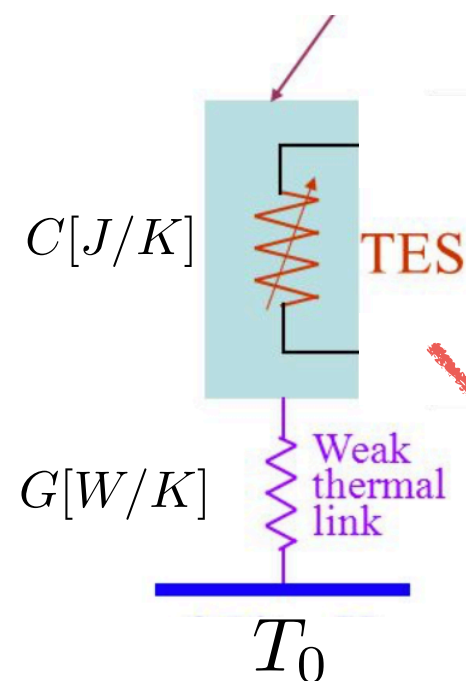
- “Termometri” che permettono di misurare **piccolissime variazioni** di **temperatura**
- Film **superconduttori** alla transizione di fase

steep $R(T)$

$$P_{\text{ott}} = C \frac{dT}{dt} + G(T - T_0)$$

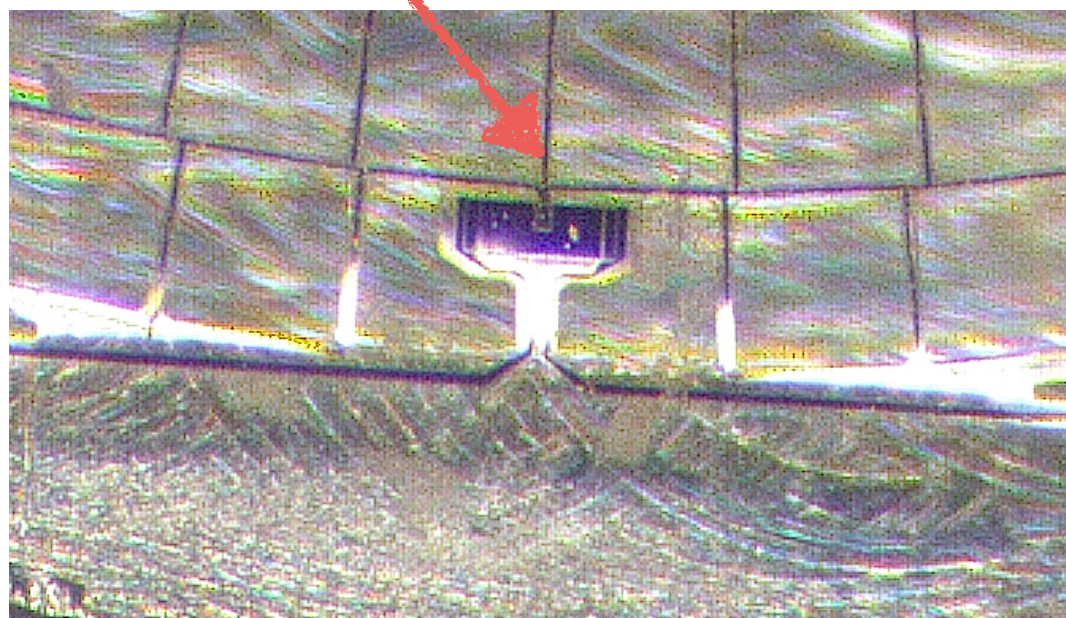


Potenza incidente



$$\frac{10 \Omega}{1 \text{ mK}} = 10^4 \Omega/K$$

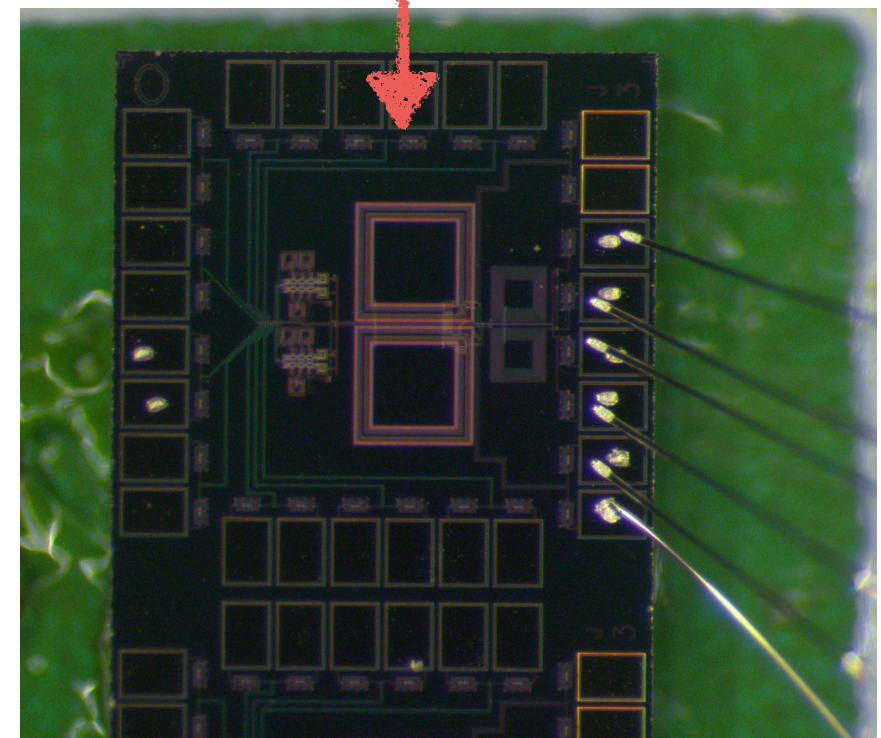
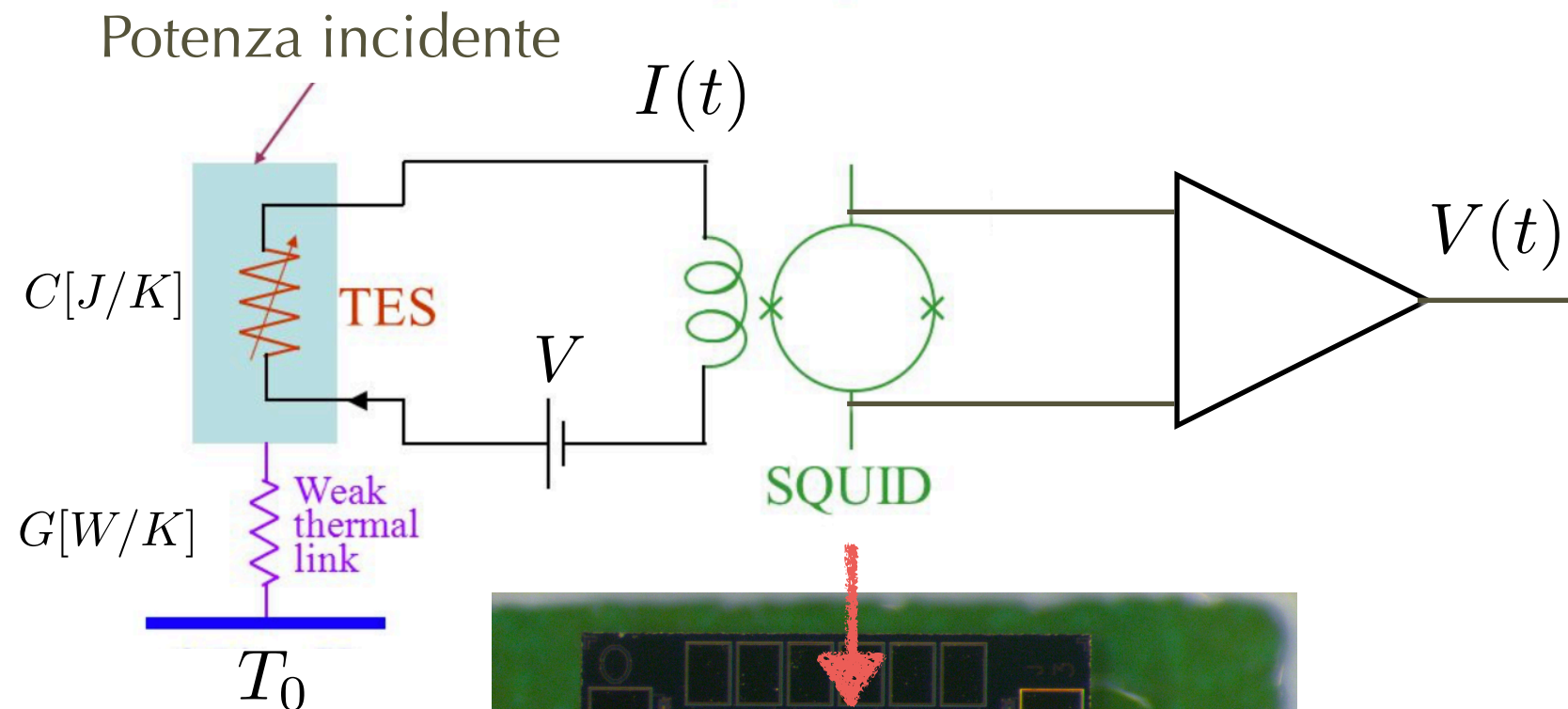
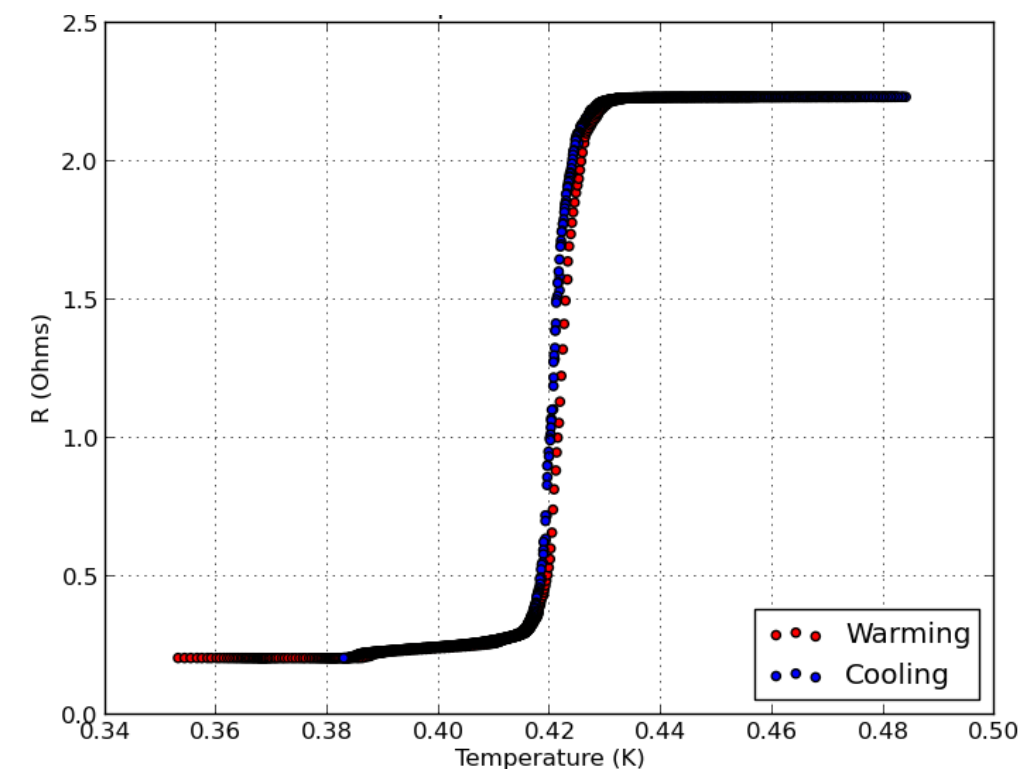
$$100 \text{ nK} \Rightarrow 1 \text{ m}\Omega$$



Transition-Edge Sensors

- “Termometri” che permettono di misurare **piccolissime variazioni** di **temperatura**
- Film **superconduttori** alla transizione di fase
- Voltage bias $\Rightarrow$ read current through SQUID

$$P_{\text{ott}} + \frac{V^2}{R} = C \frac{dT}{dt} + G(T - T_0)$$

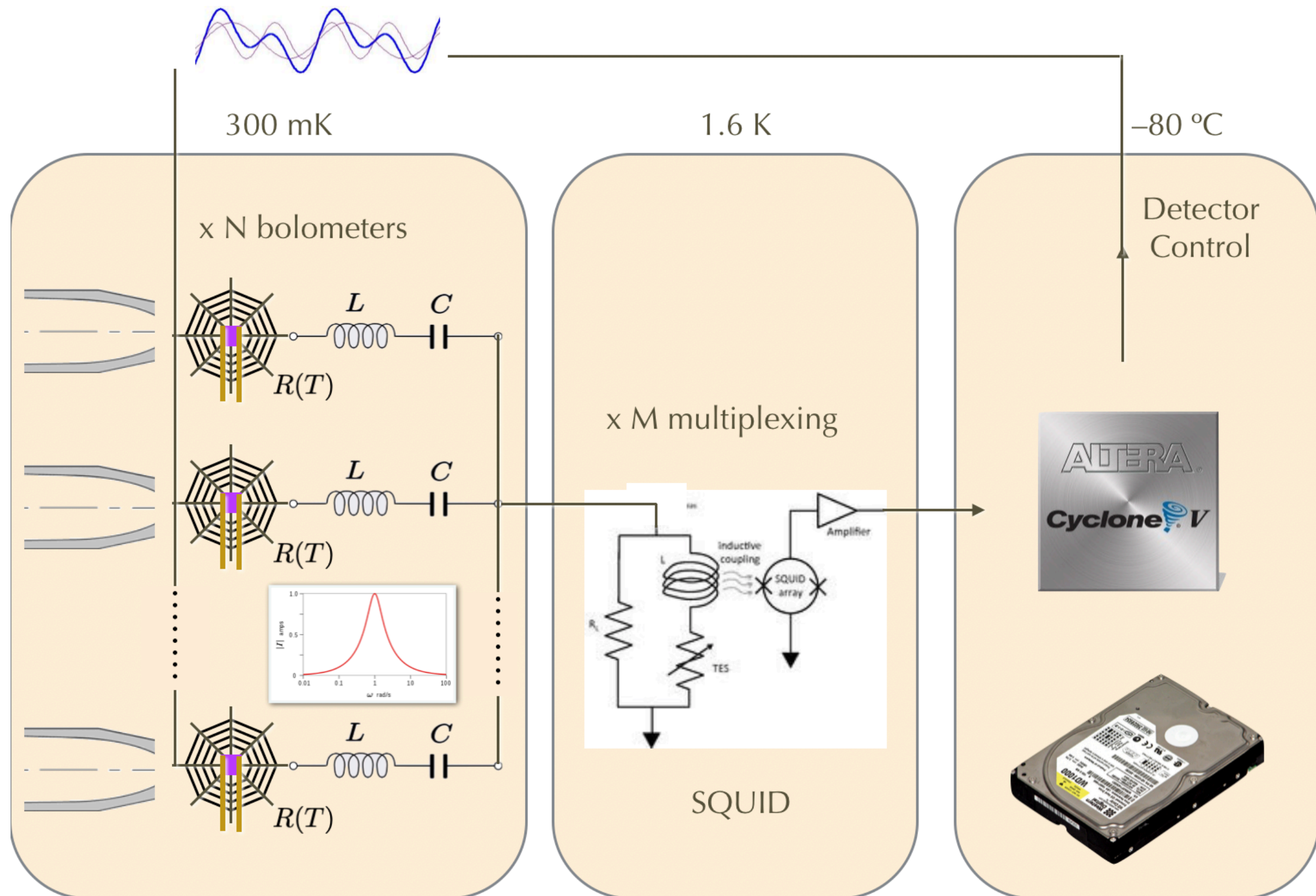


$$\frac{10 \, \Omega}{1 \, \text{mK}} = 10^4 \, \Omega/\text{K}$$

$$100 \, \text{nK} \Rightarrow 1 \, \text{m}\Omega$$

Multiplexed readout

- Tiny **cooling power** requires reading **multiple sensors** with a single pair of wires
- Each detector is coupled to a **superconducting resonant circuit**
 - Frequency-domain multiplexing (**FDM**) $\Rightarrow$ sum of sinusoids



LiteBIRD description

Siti di misura

Terra



2020

Pallone

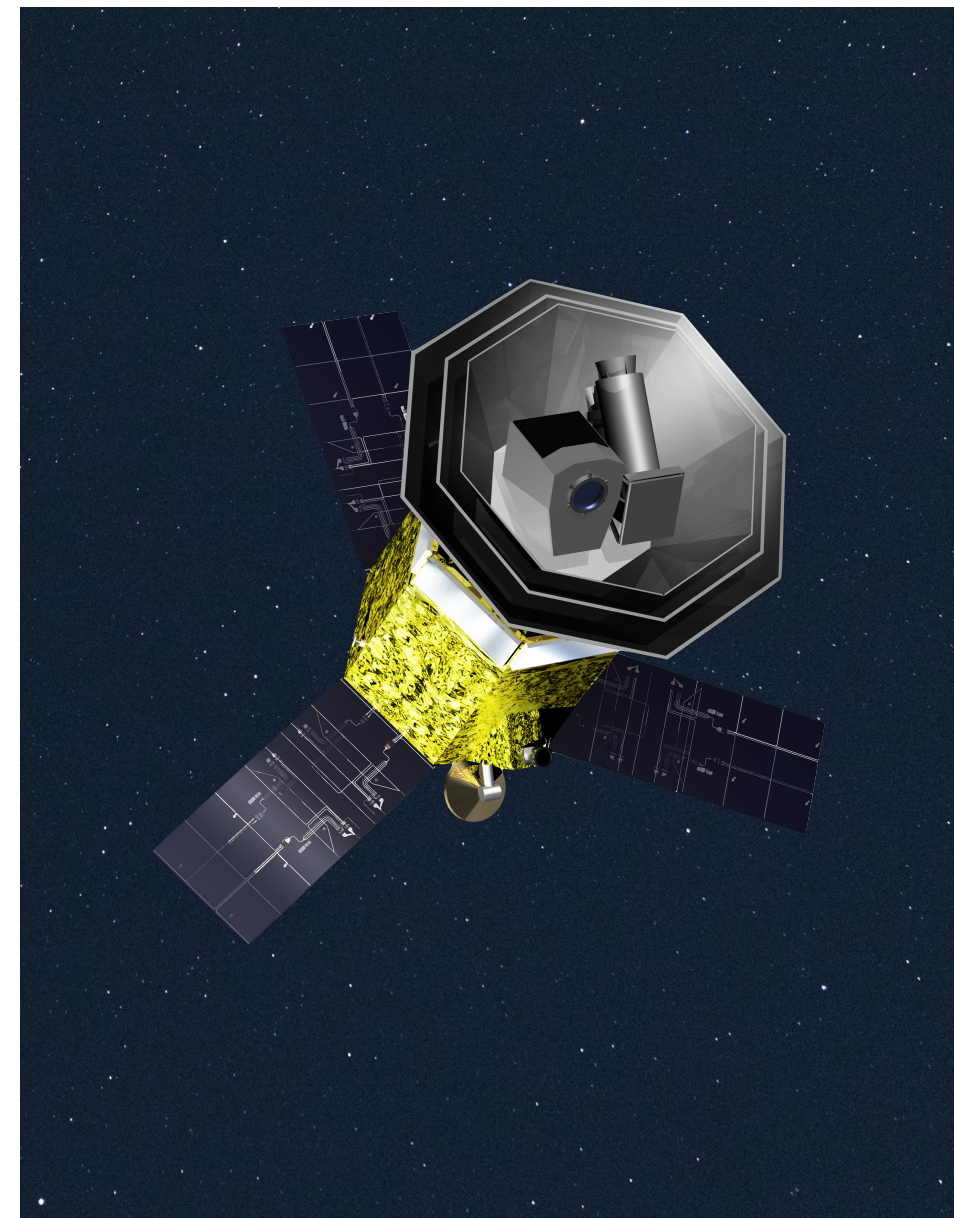


2020

LSPE/Swipe



Spazio



2028

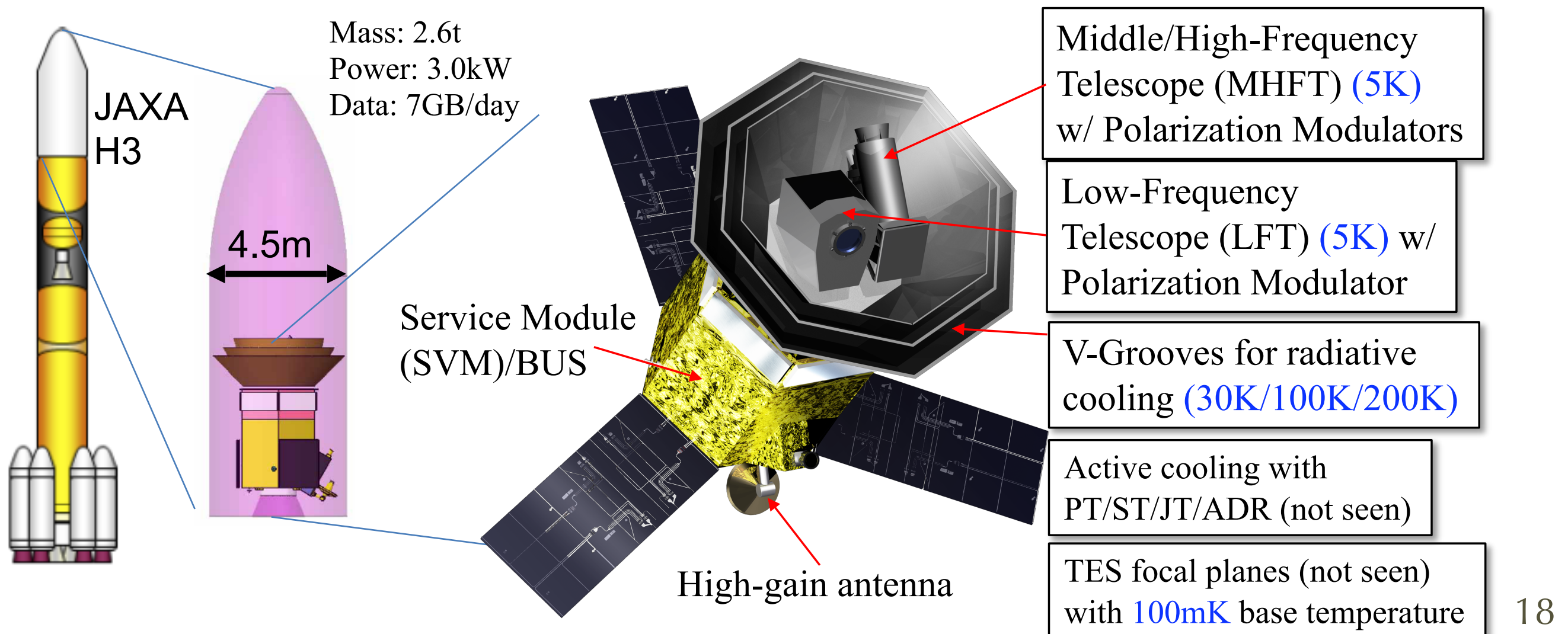
LiteBIRD



- Misura della mappa di polarizzazione nel futuro prossimo

LiteBIRD Overview

- Light satellite for B-modes from Inflation CMB Radiation Observation
- Just selected (May 2019) as the next JAXA's L-class mission
- Expected launch in 2028 with JAXA H3 rocket
 - LiteBIRD is the only CMB space mission that can be realized in 2020s
- Observations for 3 years (baseline) around Sun-Earth Lagrangian point L2
- Millimeter-wave all sky surveys (34–448 GHz, 15 bands) at 70–20 arcmin
- Mission δr (total uncertainty) < 0.001 (for $r=0$) with CMB B-mode observation



LiteBIRD mission instrument

- Three features
 - Three telescopes w/ TES arrays (4732 detectors)
 - Polarization modulator for 1/f noise reduction
 - Cryogenic system for 0.1K base temperature

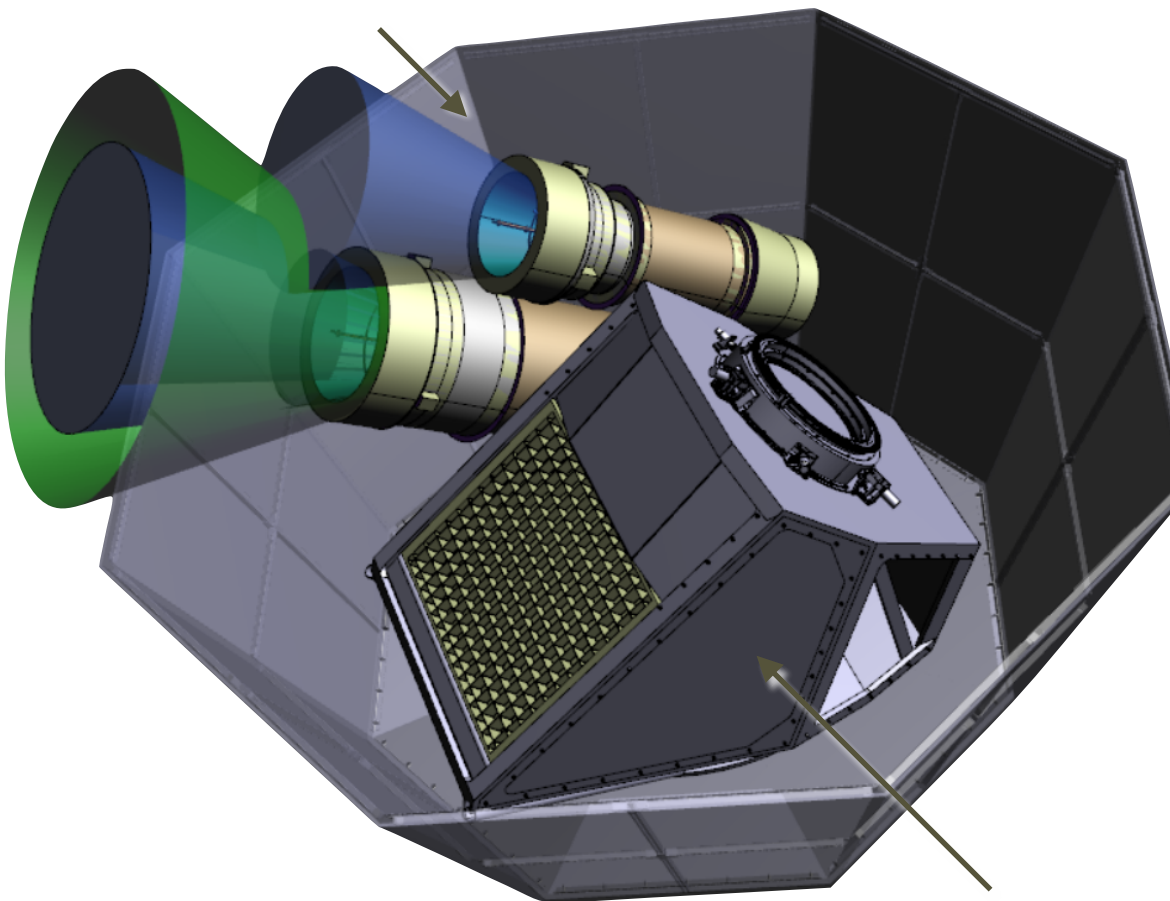
Full Success:

$$\delta r < 1 \times 10^{-3} \text{ (for } r=0\text{)}$$

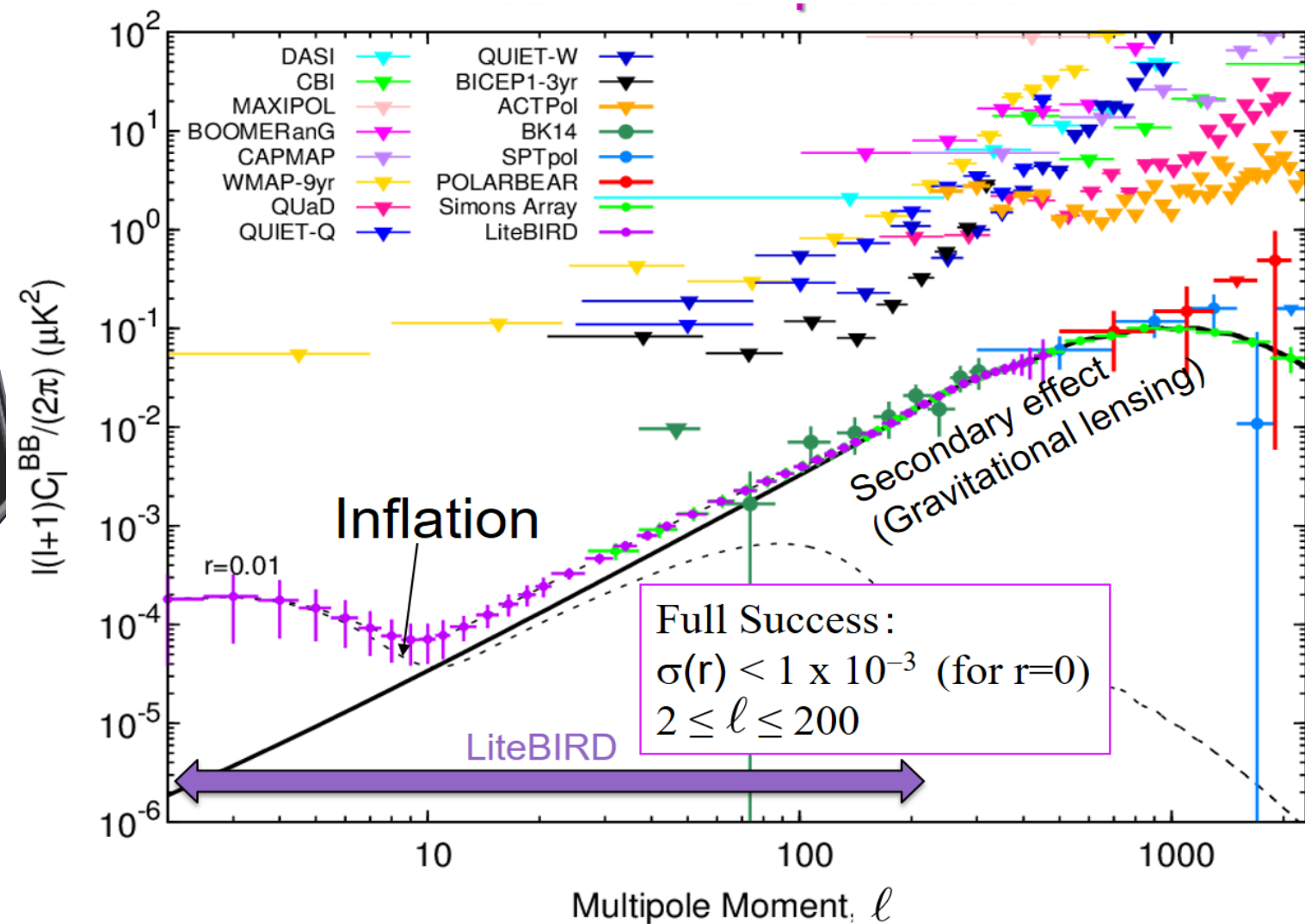
$$2 \leq \ell \leq 200$$

x70 sensitivity
w.r.t. present limit

MHFT

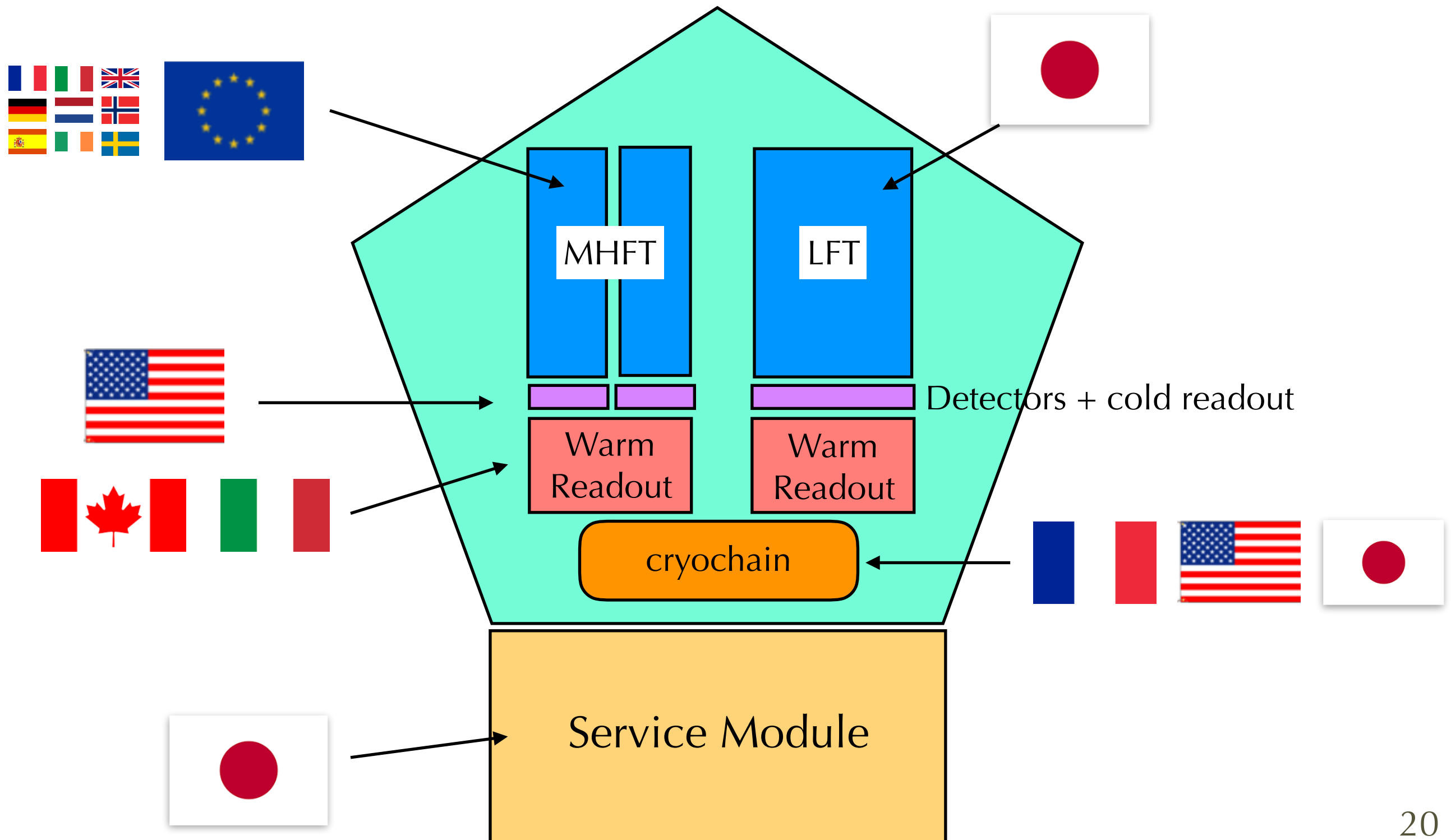


LFT



Task division

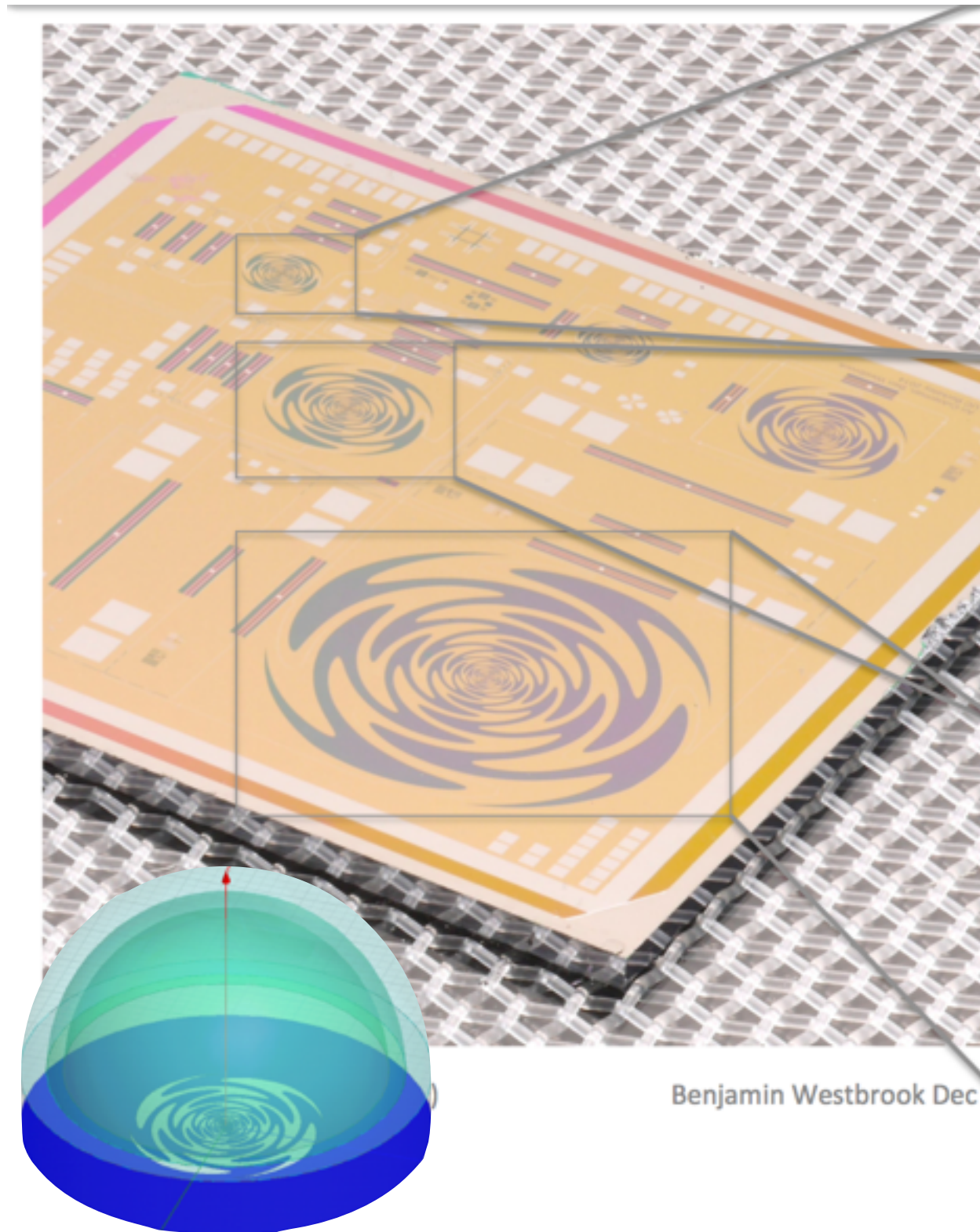
- JAXA led with strong U.S. (NASA), Canadian (CSA) and EU participation
- About 180 researchers, still growing, with CMB, x-ray, HEP, background
 - PI M.Hazumi (KEK &al), US PI A.Lee, Can PI M.Dobbs, EU PI L. Montier



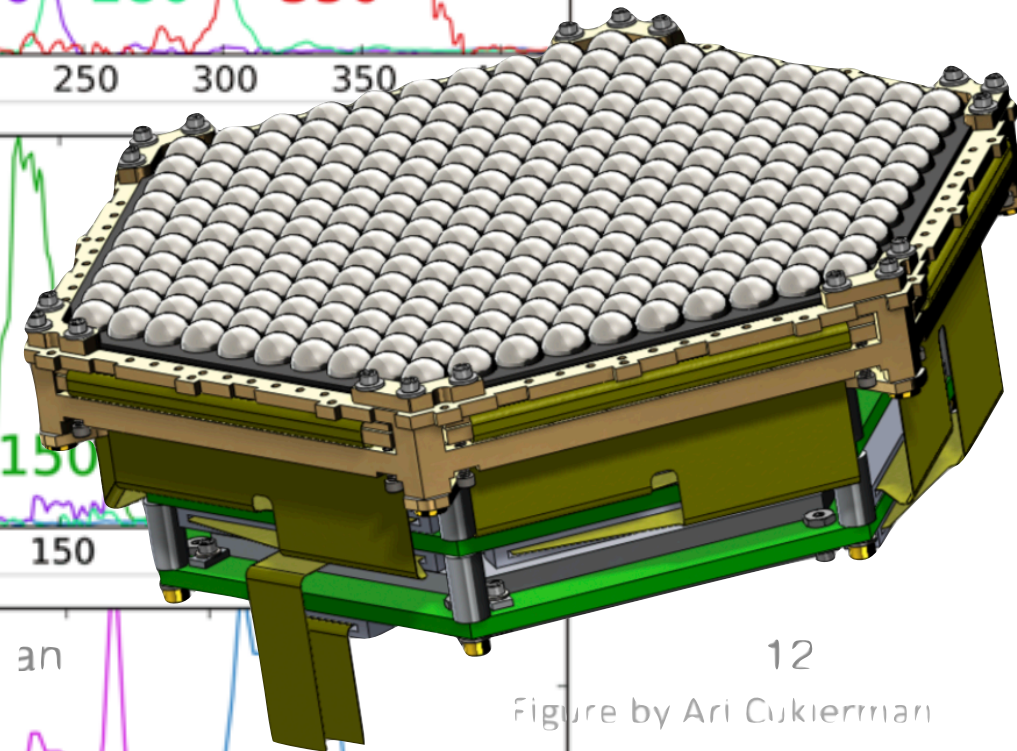
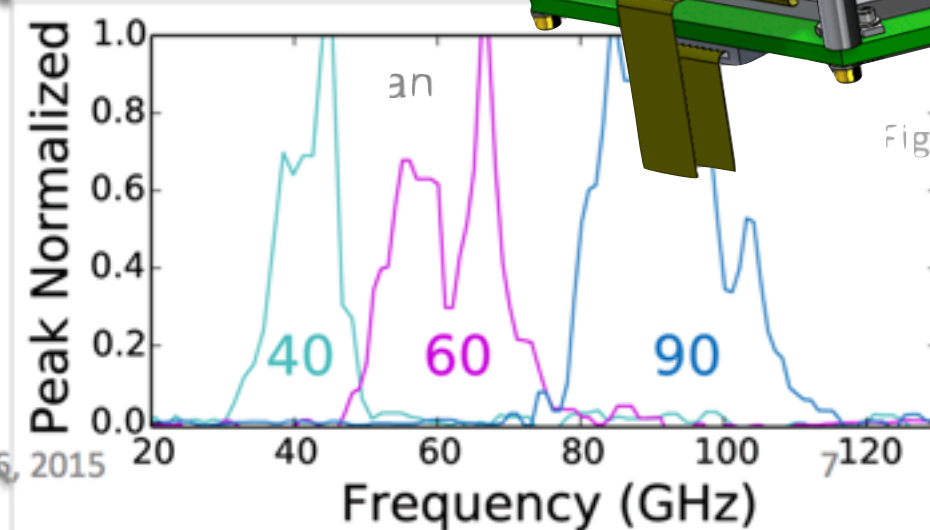
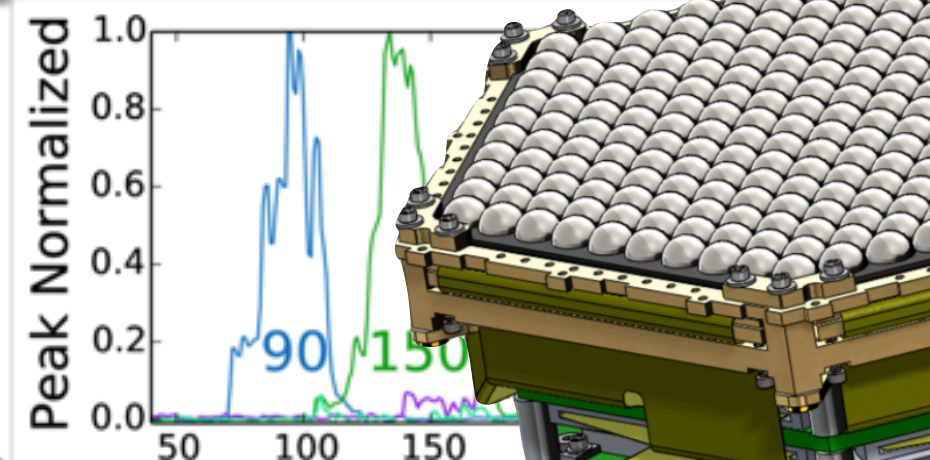
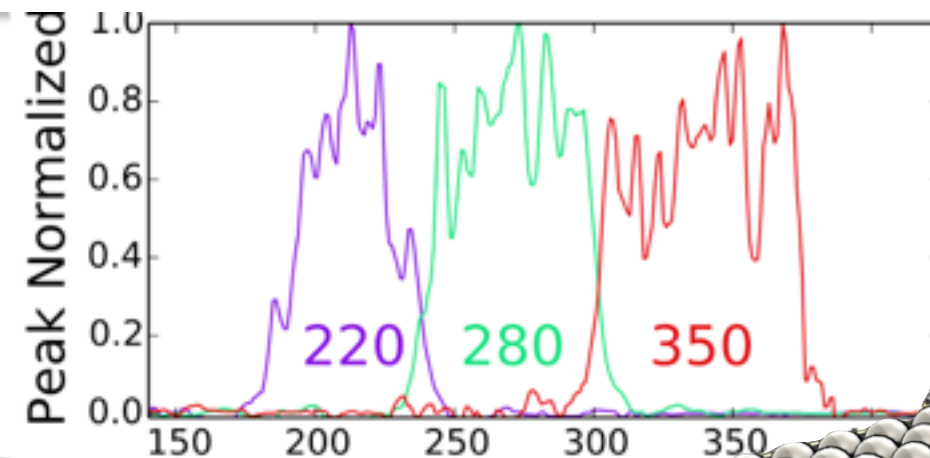


Low and mid-frequency arrays

- lenslet-coupled “trichroic pixel” = broadband sinuous antenna + filters + TES



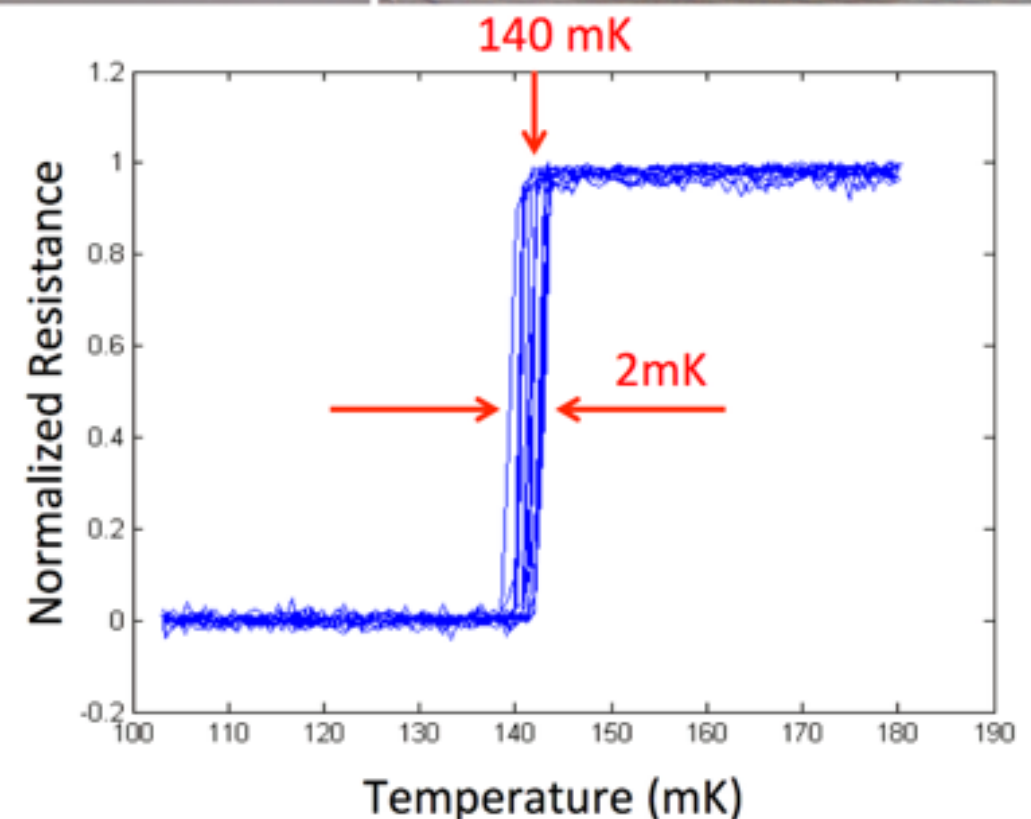
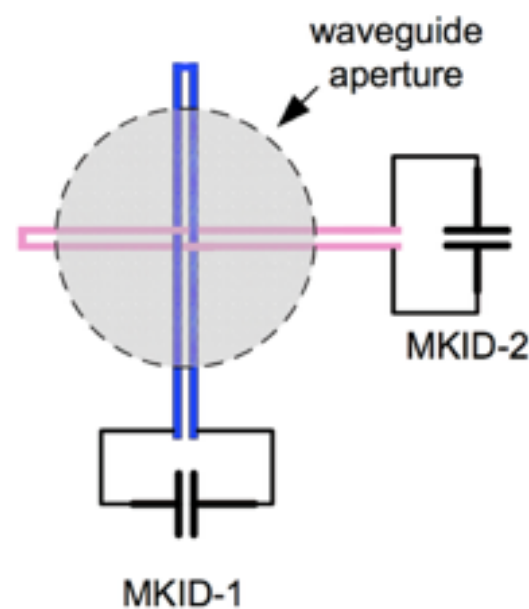
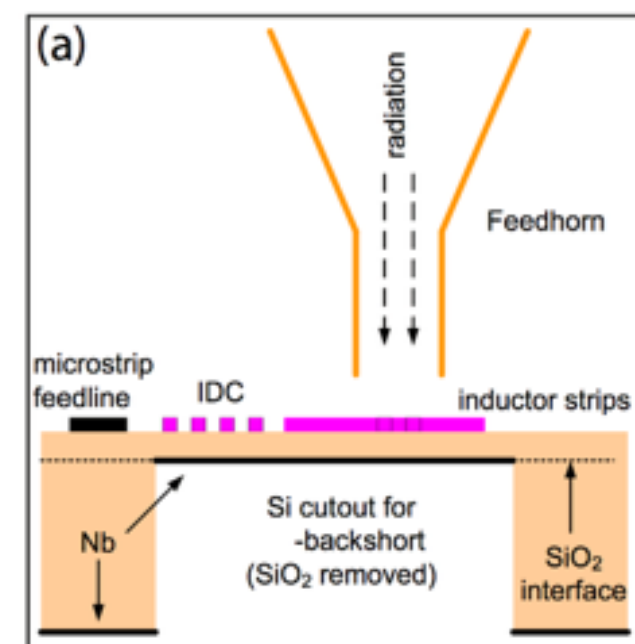
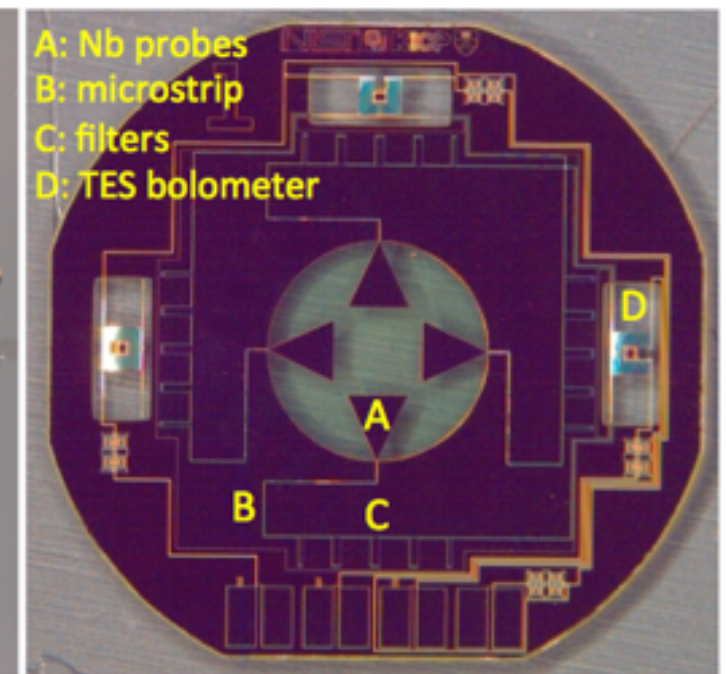
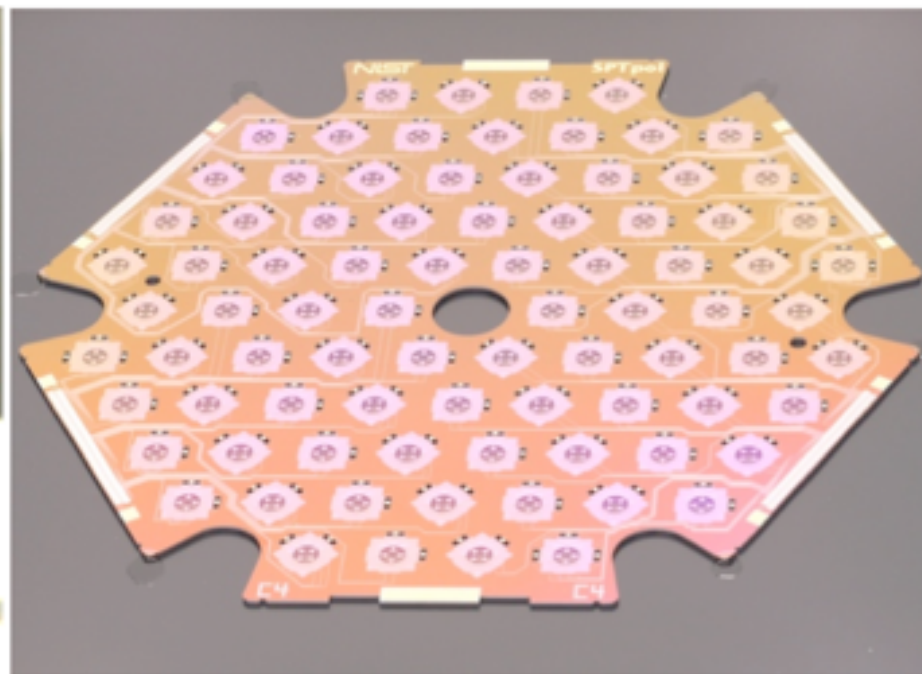
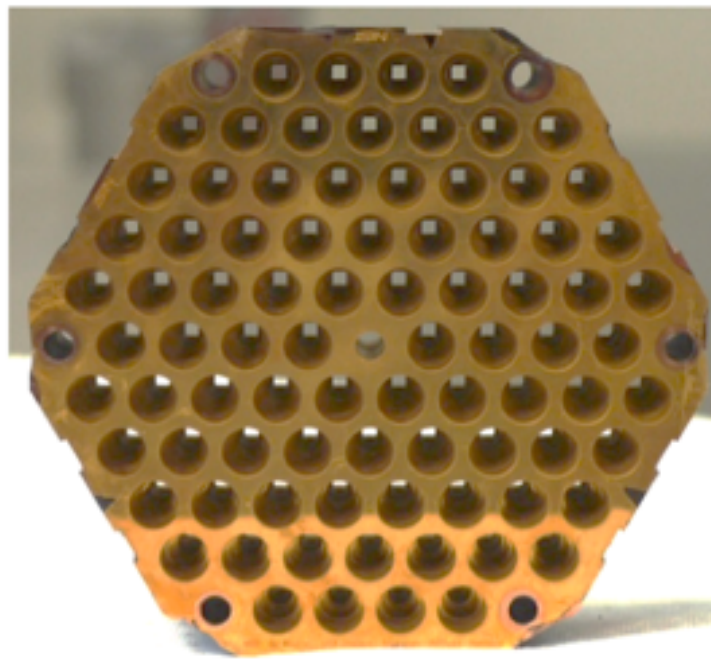
Benjamin Westbrook Dec 16, 2015



12
Figure by Ari Cukierman

High frequency array

- Antenne ortomodo litografate sensibilia alla polarizzazione lette da TES (AlMn) oppure KIDs, accoppiati con feed-horn
 - cfr. Premiale ASI/INFN

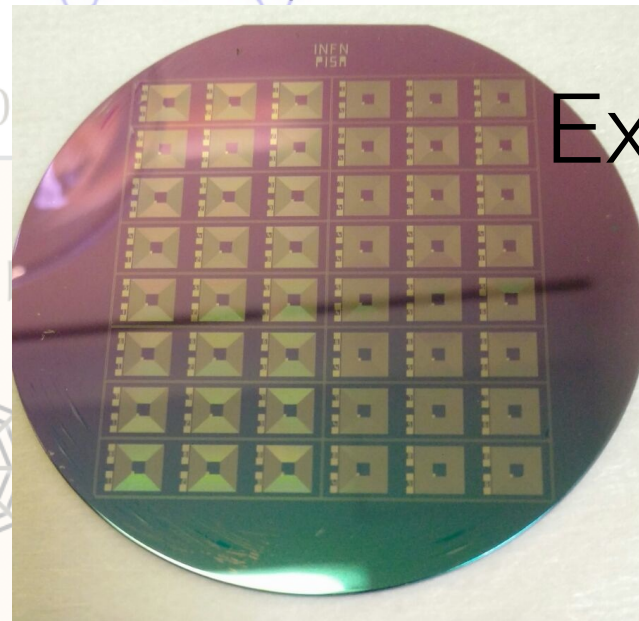
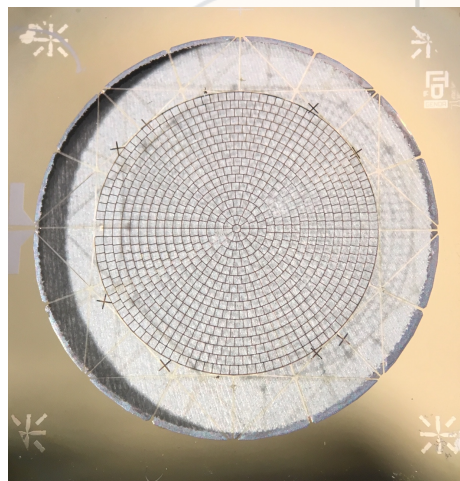


Multiplexed readout

- Tiny **cooling power** requires reading **multiple sensors** with a single pair of wires
- Each detector is coupled to a **superconducting resonant circuit**
 - Frequency-domain multiplexing (**FDM**) $\Rightarrow$ sum of sinusoids

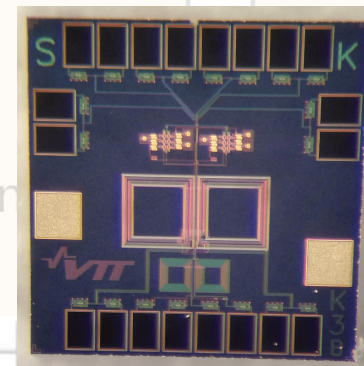
Nb LC developed at INFN/Pi SNS

INFN-GE

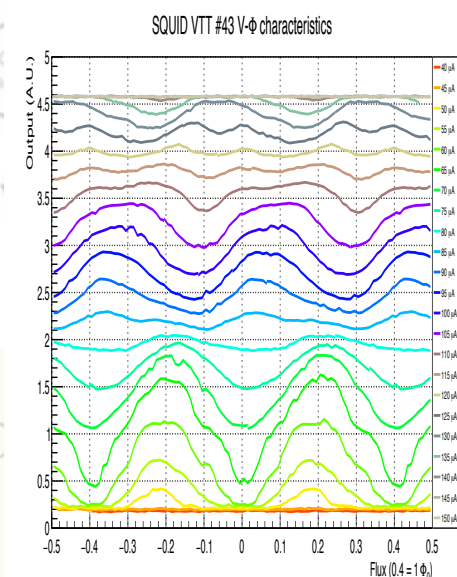
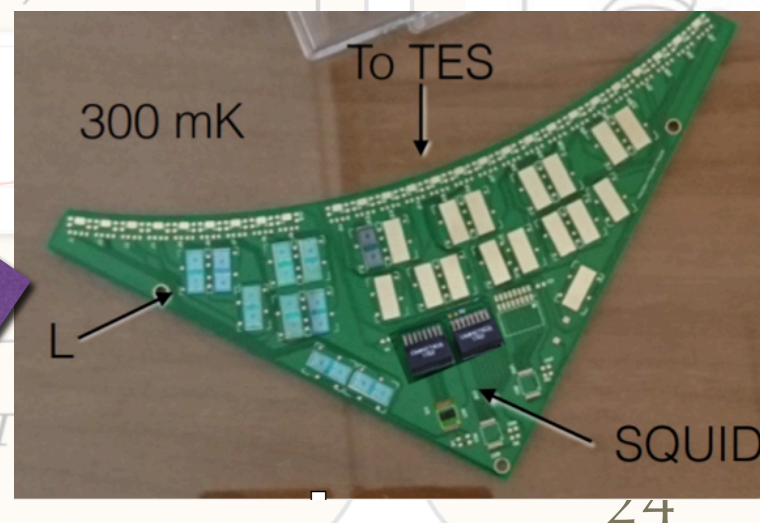
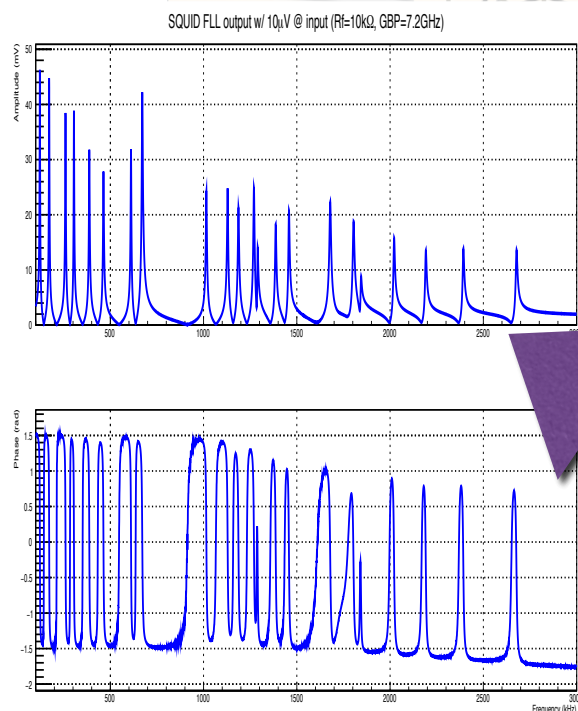
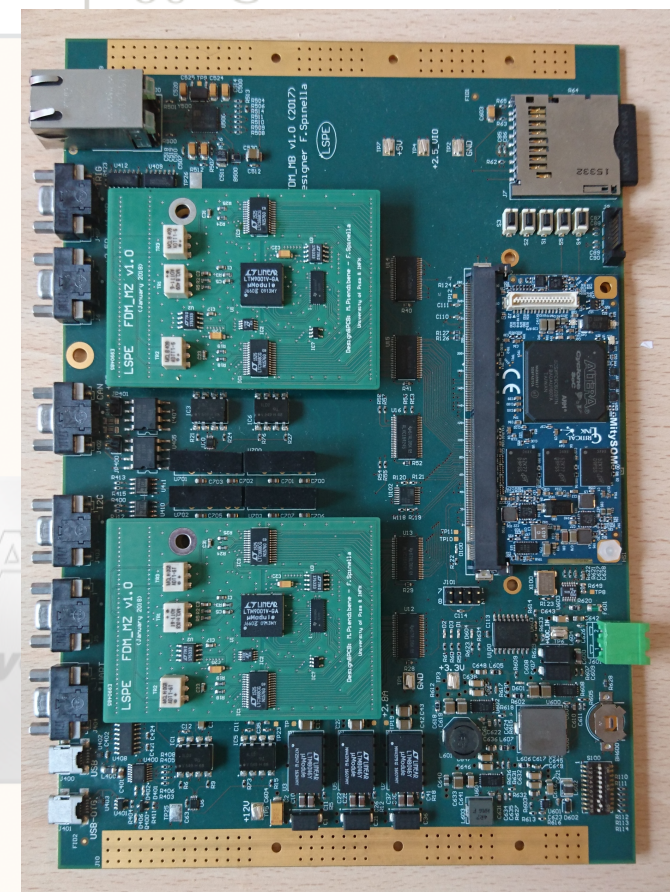


Example from LSPE

6SSA SQUID from VTT

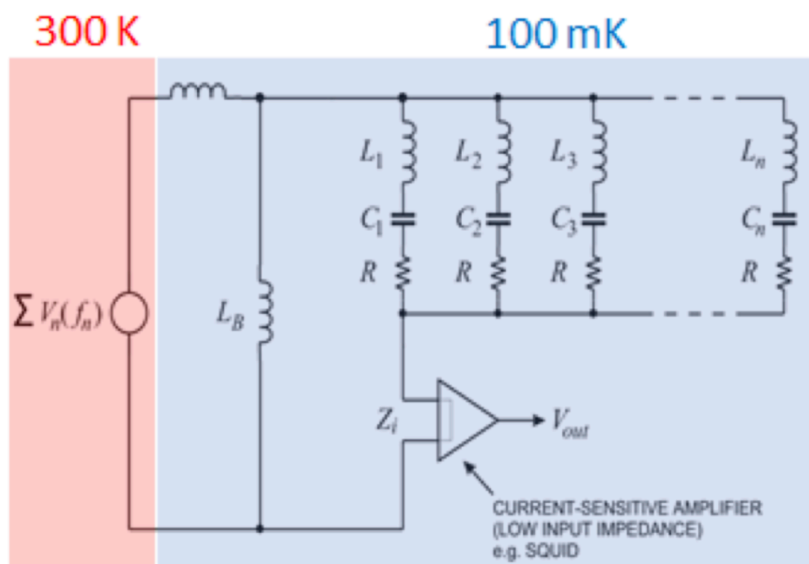
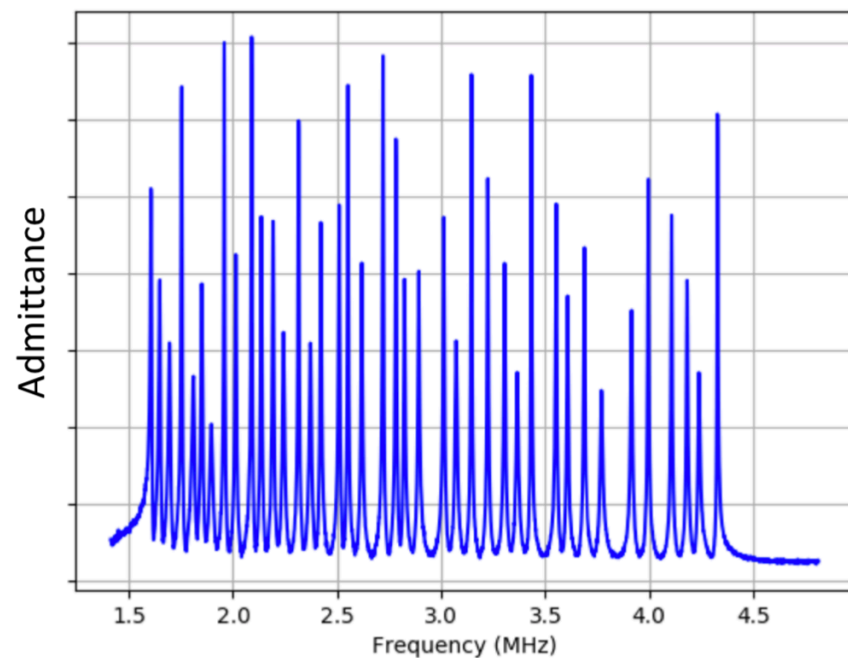
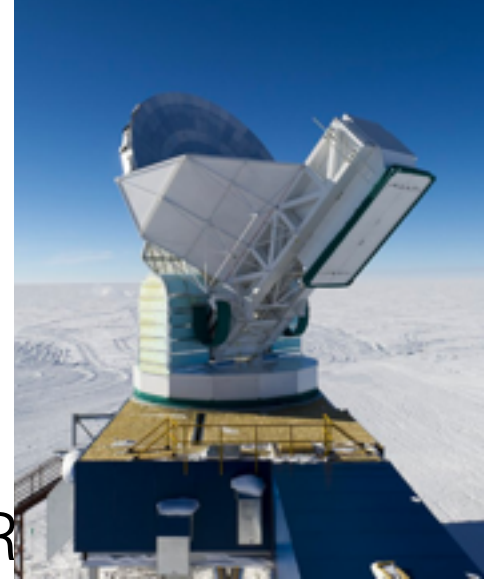


WR board INFN/PI

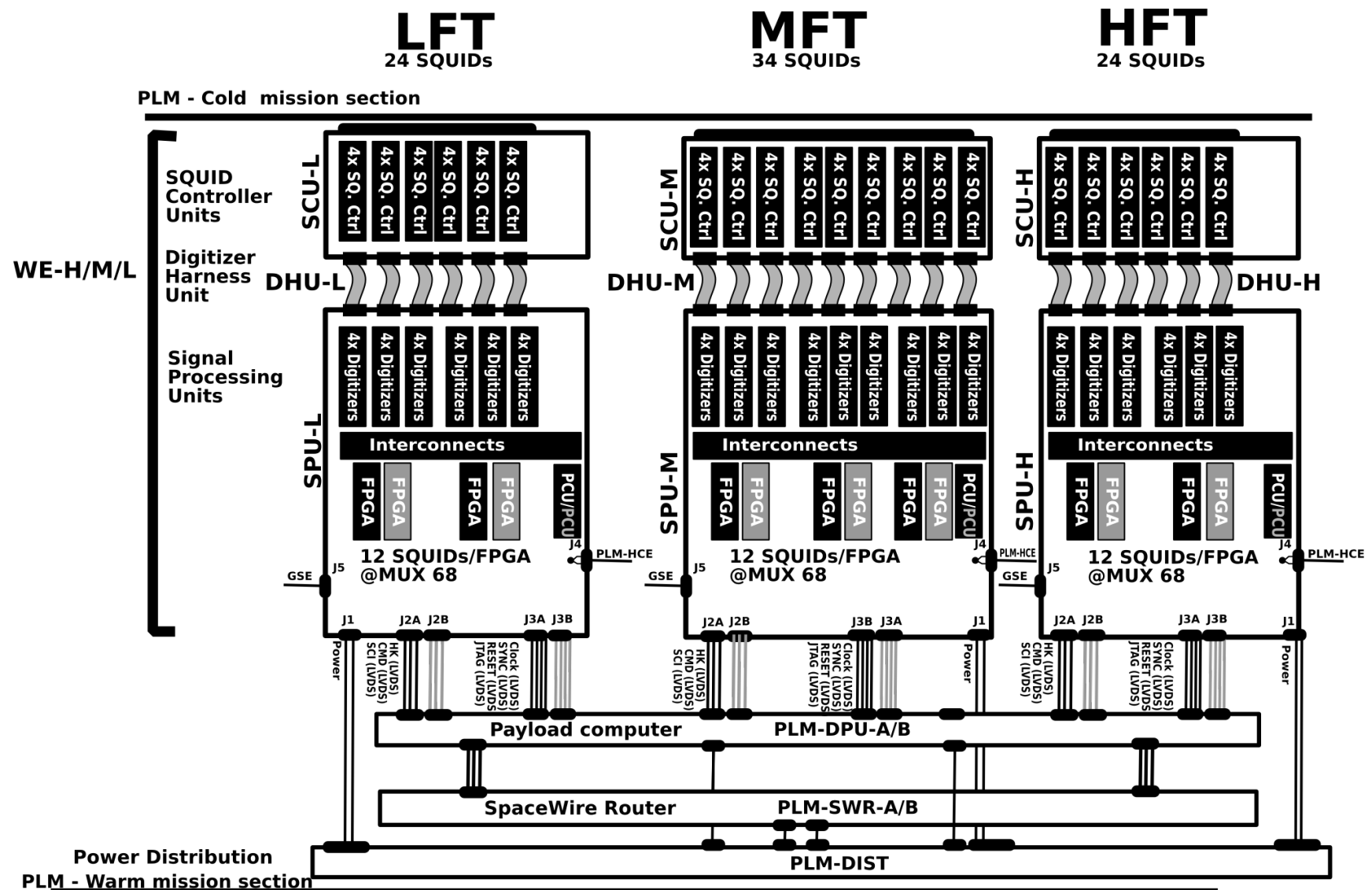


DfMUX readout

- Frequency Multiplexed **Readout** (FDM, **same as LSPE**)
 - **USA**: Cold components (**LC** boards + **SQUID**)
 - **Canada (+INFN)**: **warm** electronics
- Based on system deployed for South Pole Telescope and POLARBEAR



**Bias Circuit + LCs + Detector Array
at 100 mK stage**

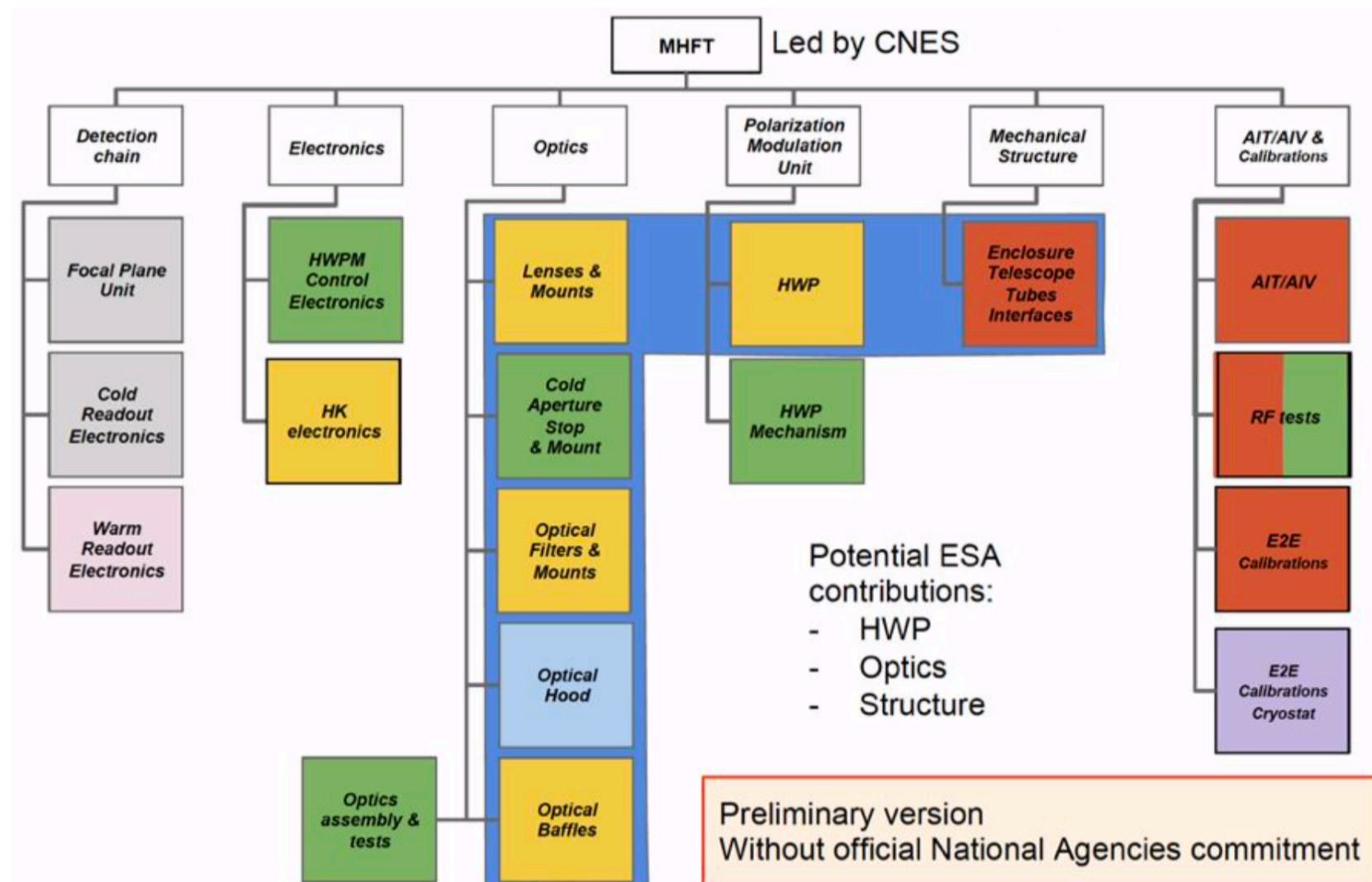


2019-05-01 - Architecture 2 - v7.svg



Il consorzio Europeo

- The **European collaboration** consists of 9 partners:
 - France, Italy, United Kingdom, Germany, Spain, Sweden, Norway, Ireland, the Netherlands, with a total of more than 100 members.
- Since 2018, we have settled a **European Steering Committee** composed of the **representatives** of all partners, and reinforced by a system engineer and an engineering team.
 - Italy has **two members**: Nicola Vittorio (RM2) e Paolo de Bernardis (RM1) ⇒ **Paolo Natoli** (FE) e **Francesco Piacentini** (RM1) from Jul/2019

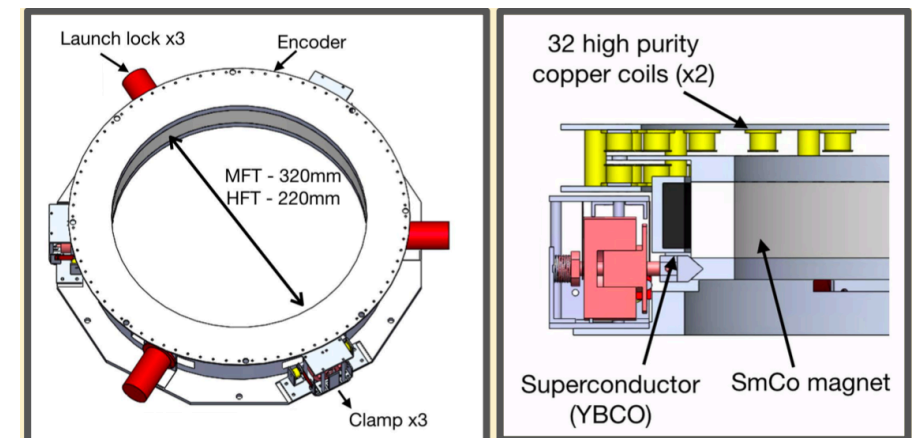


Il contributo (HW) italiano

- L'Italia è membro del [consorzio europeo](#) che è in carico di fornire il telescopio di media e alta frequenza MHFT
- Finanziamento addendum [ASI/COSMOS](#) per lo studio di fattibilità ha chiaramente identificato i seguenti items di **hardware**, in linea con la tradizione della cosmologia sperimentale/osservativa in Italia, sull'eredità di Planck

- **Rotatore di Polarizzazione** per MHFT

- HWP rotante a levitazione proposto da Roma
- Componenti dell'ottica di MHFT



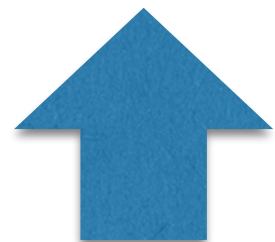
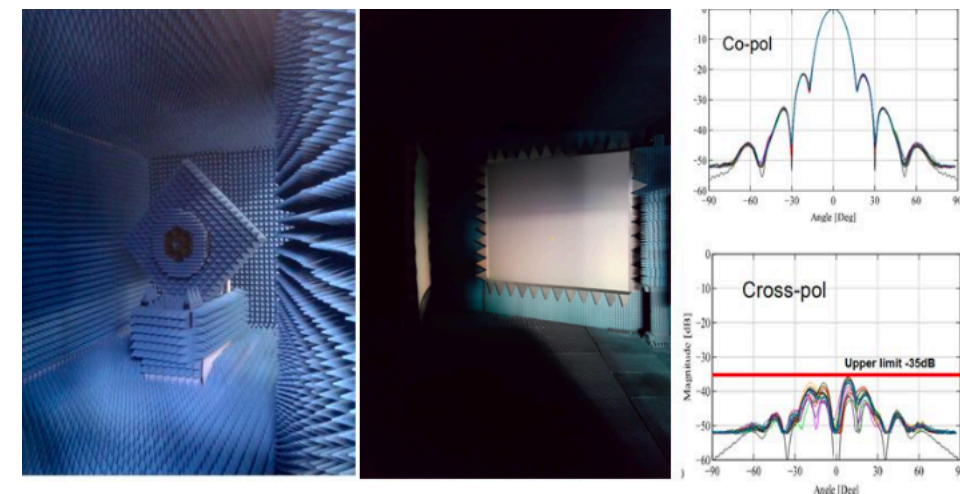
- **Calibrazioni**

- Basata sull'esperienza della sezione di Milano nella calibrazione di Planck per la Telescope Subsystem Calibration



- **Elettronica** di controllo e readout.

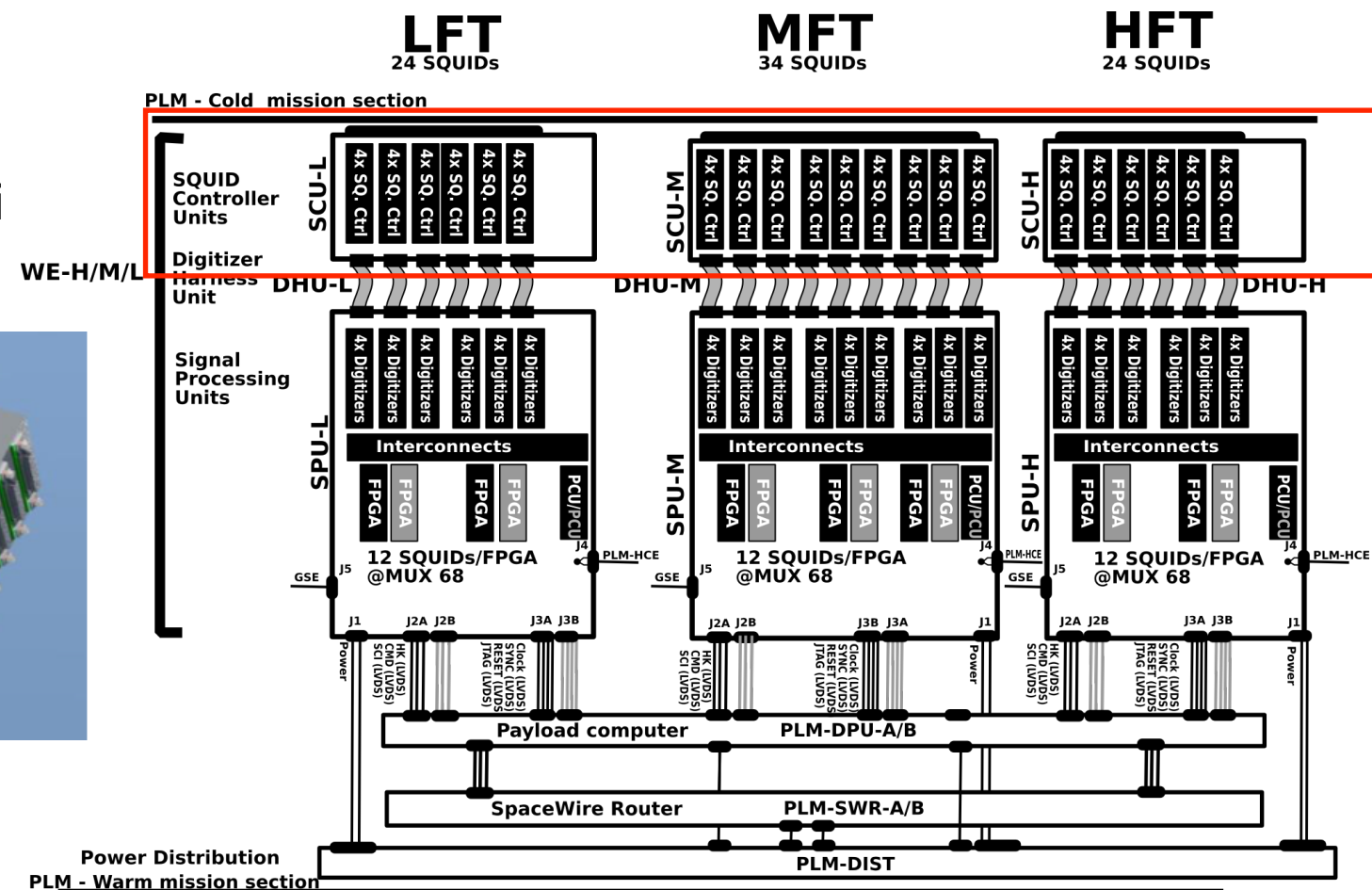
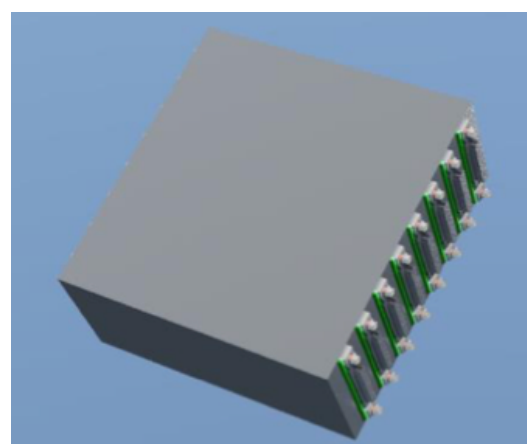
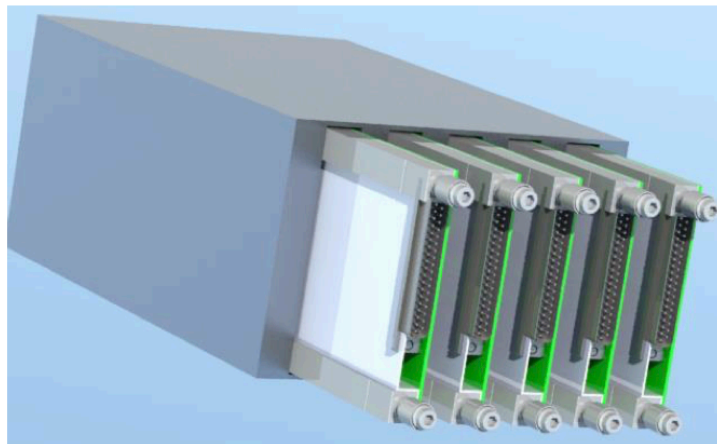
- Digital Processing Unit (in collaboration with TAS-I)
- **Detector readout**: SQUID Control Unit



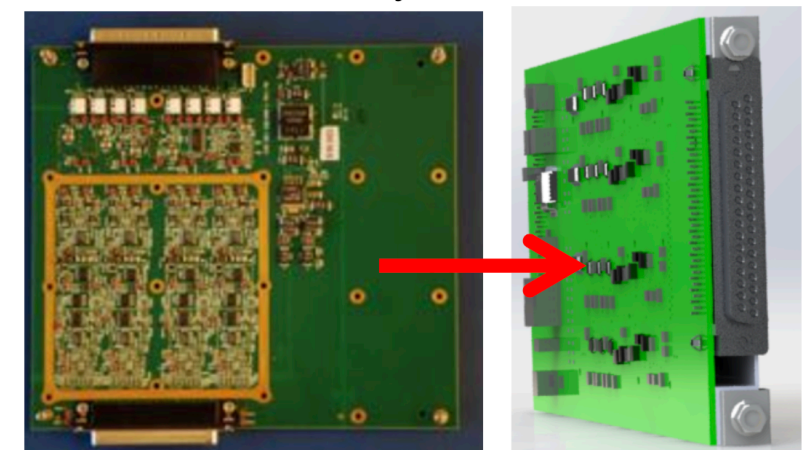
Il contributo INFN



- Il contributo INFN si inquadra nel contesto dell'**elettronica di readout** (Warm Readout electronics) :
 - Fornire le **SQUID control units** (per i tre telescopi LFT + MHFT)
 - schede elettroniche
 - meccanica di supporto
 - interfacce termiche
 - Flight **qualification** di componenti selezionati
 - qualificare per lo spazio il DAC LT1668



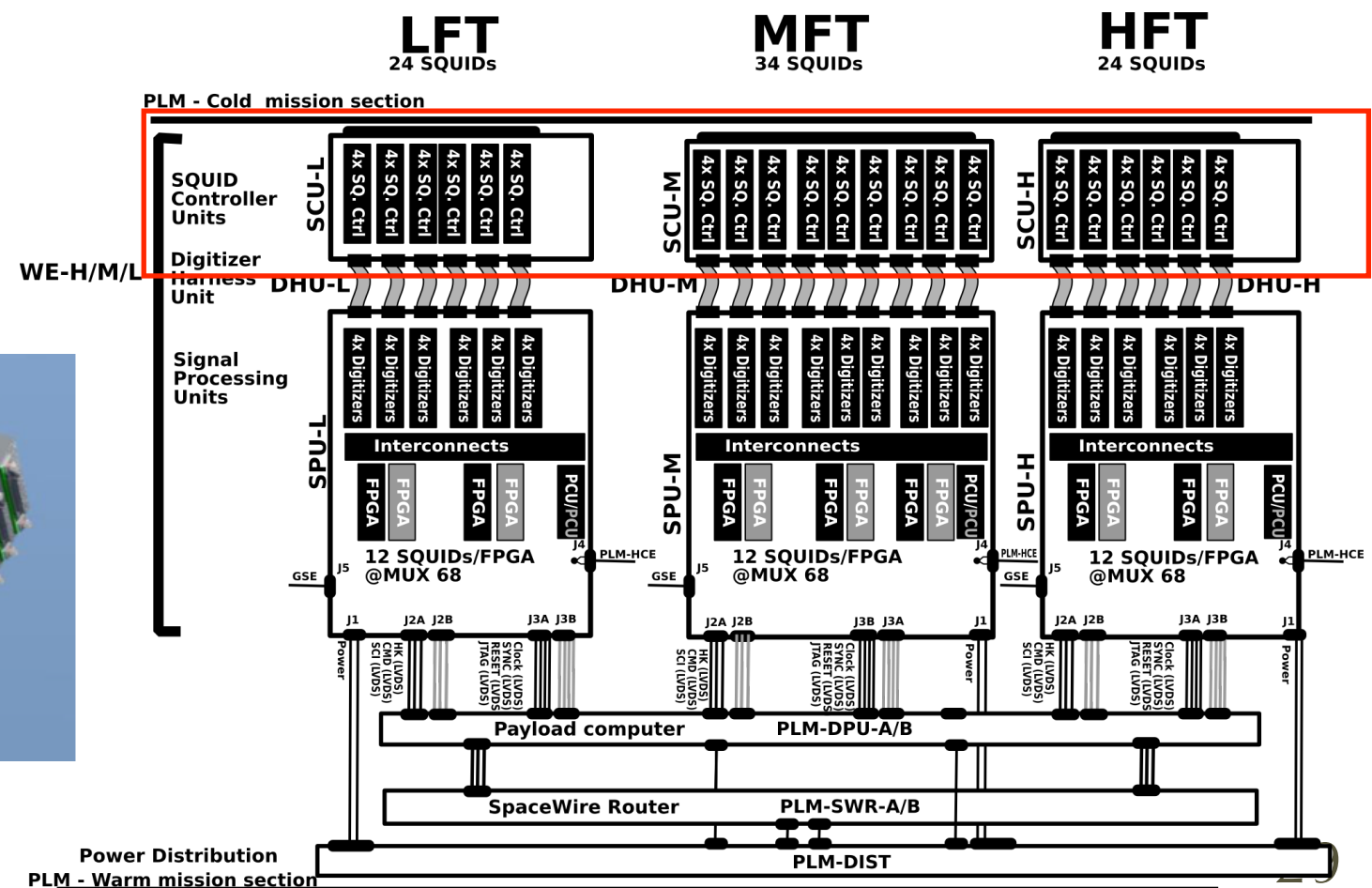
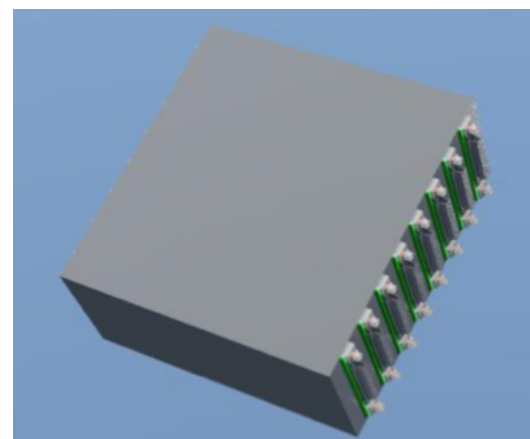
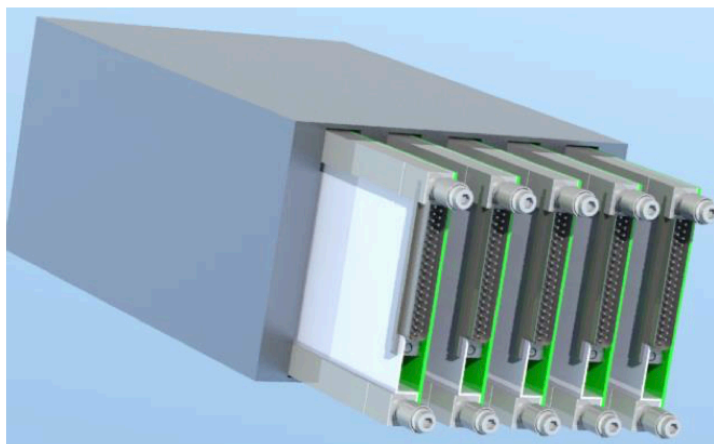
- Ulteriori contributi HW possibili
 - (**digital assembly DAC/ADC boards**)
 - DPU – in collaborazione con ASI
- In seconda battuta
 - studio della **risposta dei detector ai cosmici** (CR and/or beam tests)
 - In previsione dell'**analisi dati**
 - simulation
 - map making
 - CMB parameters extraction



SQUID readout units

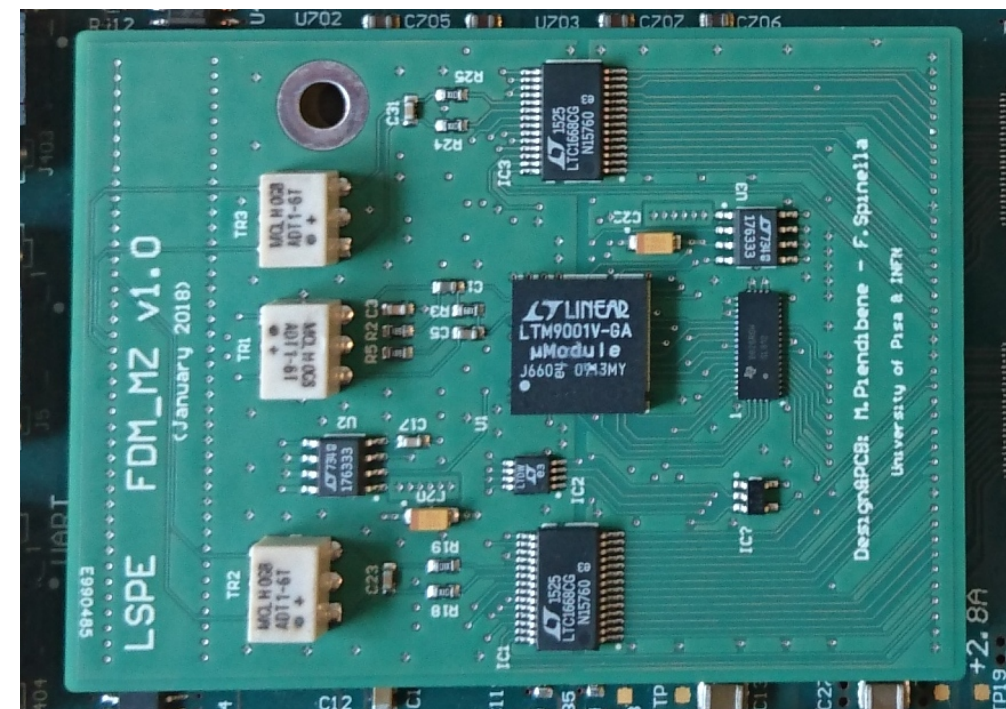
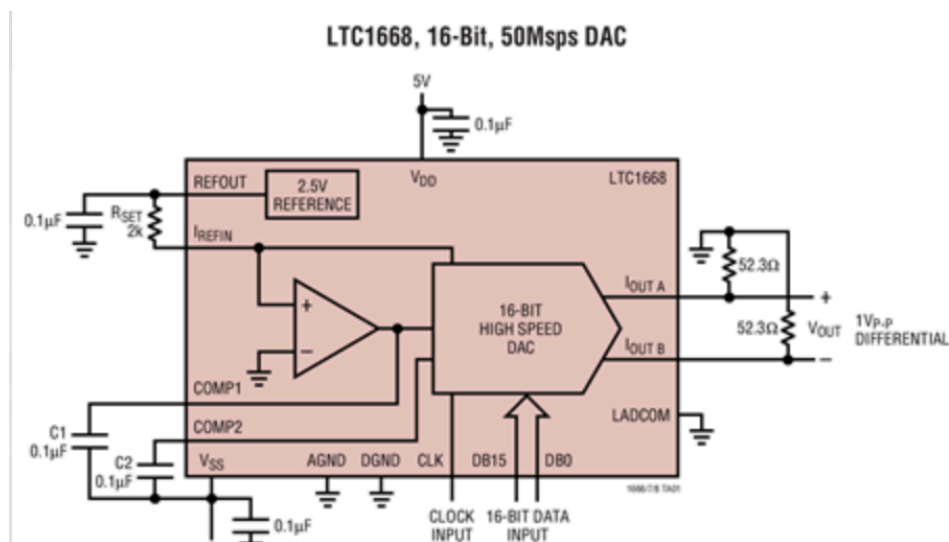


- Ci sono **4732 detectors** (multichroic TES) divisi su **3 piani focali**
 - LFT, MFT e HFT ognuno con una Signal Processing Unit (SPU)
- Una **Squid Control Unit** (SCU) per ogni SPU
 - LFT (**24 SQUIDS**), MFT (**34 SQUIDS**), HFT (**24 SQUIDS**)
- Fino ad 9 Squid Control Assembly (le boards) per ogni SCU
 - Le **Squid Control Boards** forniscono l'interfaccia fondamentale fra i rivelatori e il readout (4 SQUID/each)
- Partendo dall'attuale versione per SPT, le unità vanno
 - ridisegnate
 - testate a caldo
 - testate a freddo (SQUID @100mK)
 - Prodotti i DM, EQM e FM
 - Documentati



Flight qualification

- The Digitizer Assembly (DA) uses the **AD768 DAC** to generate the carrier and nuller signals. It was selected due to its low 1/f noise and its availability as a **space qualified** component.
 - However, this DAC is **power hungry**, and accounts for a non-negligible part of the WE power budget.
 - An alternate DAC, the **LT1668**, offers the same performance with at least half of the power consumption, but is not space qualified.
- LT1668 presently being **used in LSPE** warm readout
 - test fino a **30 krad** con particelle ionizzanti
 - acceptable system performance
 - 1/f noise & white noise
 - Linearity & monotonicity
 - Power consumption
 - Radiation behavior (transients, latch-ups etc.)

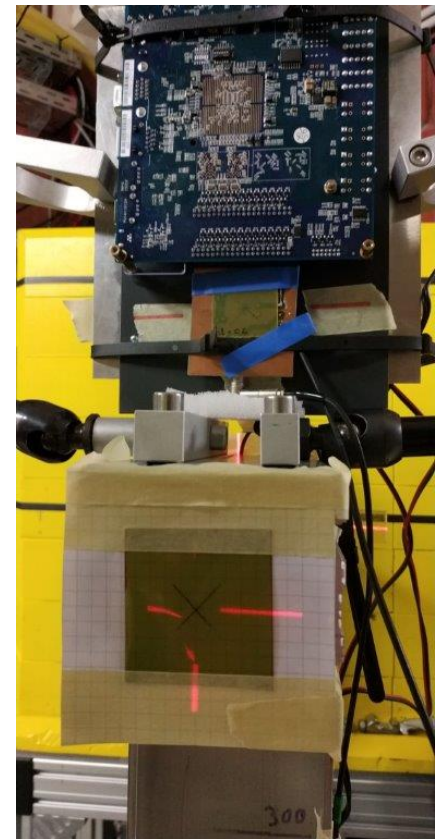
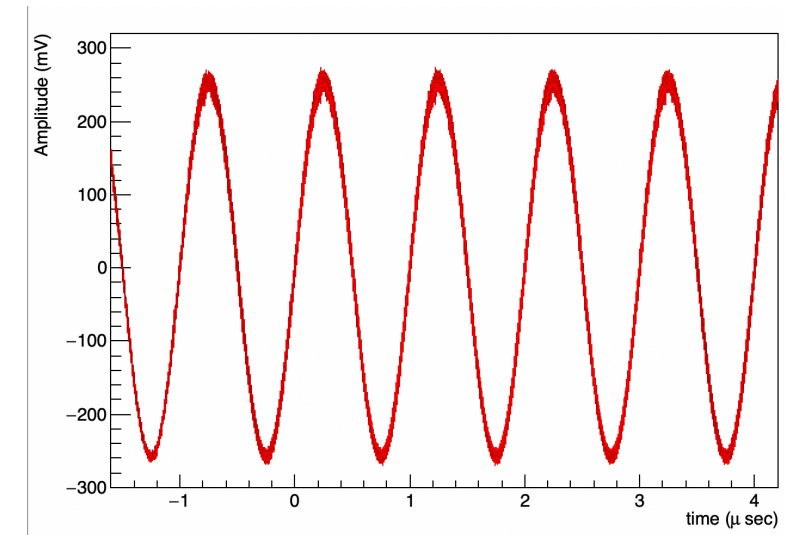


Le Sezioni INFN Partecipanti

- Molti gruppi in **Italia** già impegnati con **finanziamento ASI**
- Vogliamo esplicitare un coinvolgimento di pochi **gruppi INFN** impegnati sull'**hardware**, in particolare sul **Warm Readout**
 - Divisione “fluida”
 - possibilità di incrementare il contributo con altri items
 - ci aspettiamo nel corso dei prossimi anni di incrementare il contributo dal punto di vista della simulazione e dell’analisi
- **Pisa** (G. Signorelli, Resp. Nazionale)
 - **Coordinazione** del contributo INFN
 - **Space qualification** dei componenti - misure e analisi
 - **SQUID control unit** (electronic development, mechanical, thermal)
- **Milano Bicocca** (M. Zannoni)
 - **SQUID control unit** (electronic development)
 - simulazione del **danno da radiazione**
- **Ferrara** (P. Natoli)
 - **SQUID control unit** and readout simulation
 - Impatto del noise sulle performance dell’esperimento.
- **Roma 1** (L. Lamagna)
 - Partecipazione ai test

Attività prevista per il 2020

- **Qualifica** del DAC LT1668
 - Realizzazione di **prototype-boards**
 - **Simulazione** del danno da **radiazione**
 - Test su **fascio** (PSI - Legnaro - Dresda - Calliope)
 - Preparazione del **report** di compatibilità
 - Attività da cominciare il prima possibile, anticipabile al 2019
- **Squid Control Units**
 - Realizzazione di **schede prototipo** basate sull'attuale disegno
 - **Semplificazione** del disegno elettronico
 - **Simulazione** della catena di SQUID readout
 - Studio dell'**interfaccia meccanica**
 - Studio dell'**interfaccia termica**
 - Stima con partner industriale del framework temporale-economico
 - Preparazione delle test facility
 - warm
 - criogenica
- Simulazione dell'interazione detector-**raggi cosmici**
- Studio dell'impatto del **rumore dei rivelatori** e della catena elettronica sulle **performance scientifiche** dell'esperimento



Anagrafica Pisa LITEBIRD

RICERCATORI

Giovanni Signorelli	R.N. R.L.	0.60
Alessandro Baldini		0.20
Donato Nicolò		0.30
Luca Galli		0.10
Andrea Tartari (Art. 36 ASI/COSMOS)		0.50

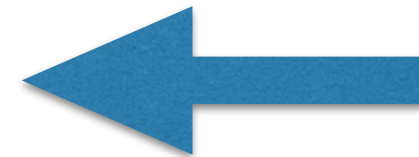
TECNOLOGI / TECNICI

Franco Spinella (Tecnol. Elettronico)	0.10
Andrea Moggi (Progett. Meccanica)	0.10

ASSEGNISTI

Davide Vaccaro	0.50
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TOTALE	2.40
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ALTRI SERVIZI

Officina meccanica	2 m.u
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Richieste alla sezione

- **Qualifica** del DAC LT1668
 - elettronica: progettazione di schede di test
- **Squid Control Units**
 - elettronica: prototipi (in collaborazione con MIB)
 - **meccanica**: Studio dell'**interfaccia meccanica e termica con il satellite**)
 - cryofacility dedicata
 - laboratorio?

Finanziamento richiesto per il 2020

- Qualifica del DAC LT1668
 - Realizzazione di prototype-boards 5k
 - Simulazione del danno da radiazione
 - Test su fascio (PSI - Legnaro - Dresda - Calliope ENEA) 10k 1 settimanaAltri consumi
 - Preparazione del report di compatibilità
 - Attività da cominciare il prima possibile, anticipabile al 2019
- Squid Control Units
 - Realizzazione di schede prototipo basate sull'attuale disegno 10k
 - Semplificazione del disegno elettronico
 - Simulazione della catena di SQUID readout 2k
 - Studio dell'interfaccia meccanica 3k
 - Affitto facility per vibrazioni 5k
 - Studio dell'interfaccia termica
 - Stima con partner industriale del framework temporale-economico 20k÷30k altri consumi n.a.c.??
 - Preparazione delle test facility
 - warm
 - criogenica 60kEUR
 - comprare SQUID US 10kEUR (500US\$/each)
- Simulazione dell'interazione detector-raggi cosmici (SW 5k)
- Studio dell'impatto del rumore dei rivelatori e della catena elettronica sulle performance scientifiche dell'esperimento
- Missioni

FINE

Hi Giovanni,

We do indeed now produce dilutor modules. They are not yet fully commercial, but we are making rapid progress in this. The current systems will run continuously from a mechanical pre-cooler platform, achieve a base temperature of around 75mK, and will run at 100mK under a few microWatts of load. we hope soon to improve on this.

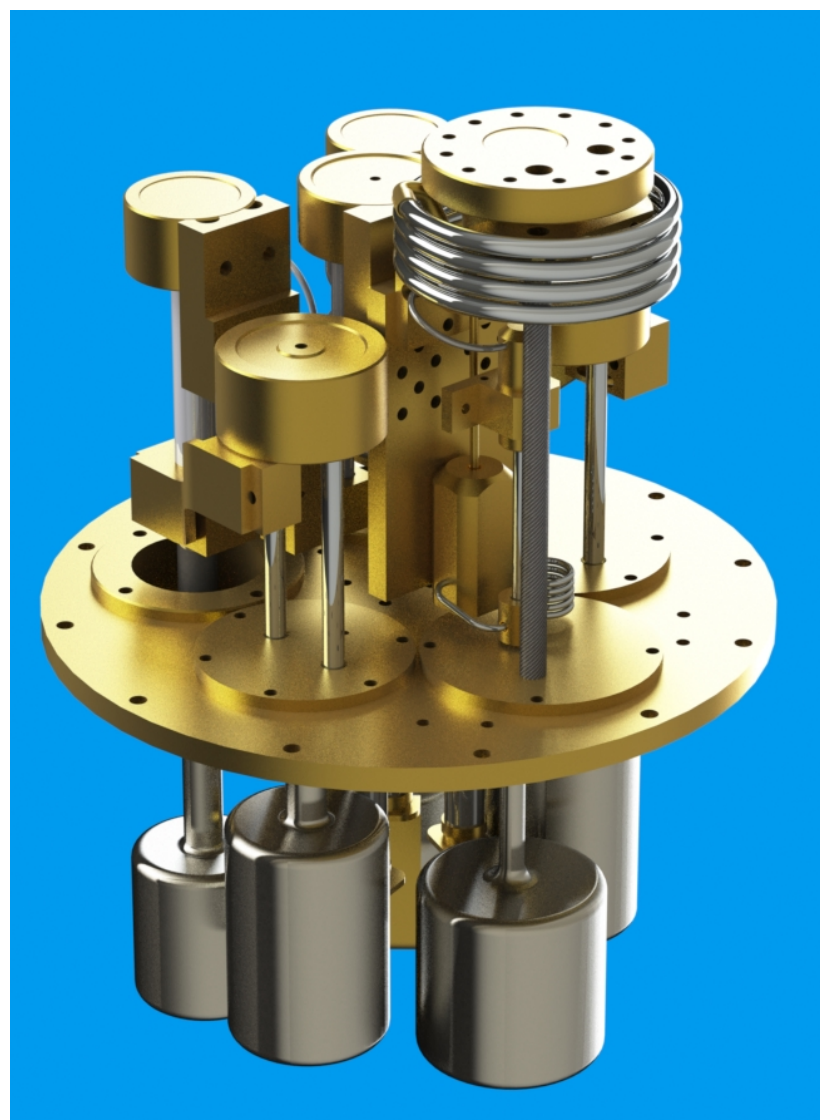
I have attached a picture (Solidworks render) of the current iteration of what we refer to as A 'CC-' cooler. The picture is upside down compared to the operating orientation, of course, as the cold heads must point downwards when it is running.

The circular main interface plate (mainplate) is 17cm in diameter, and the entire cooler system is about 24 cm tall. It is fully modular, so it is easy to replace the dilutor module, for example. The sorb pumps are below the mainplate in this picture, as is the expansion tank for the dilutor mix (front middle).

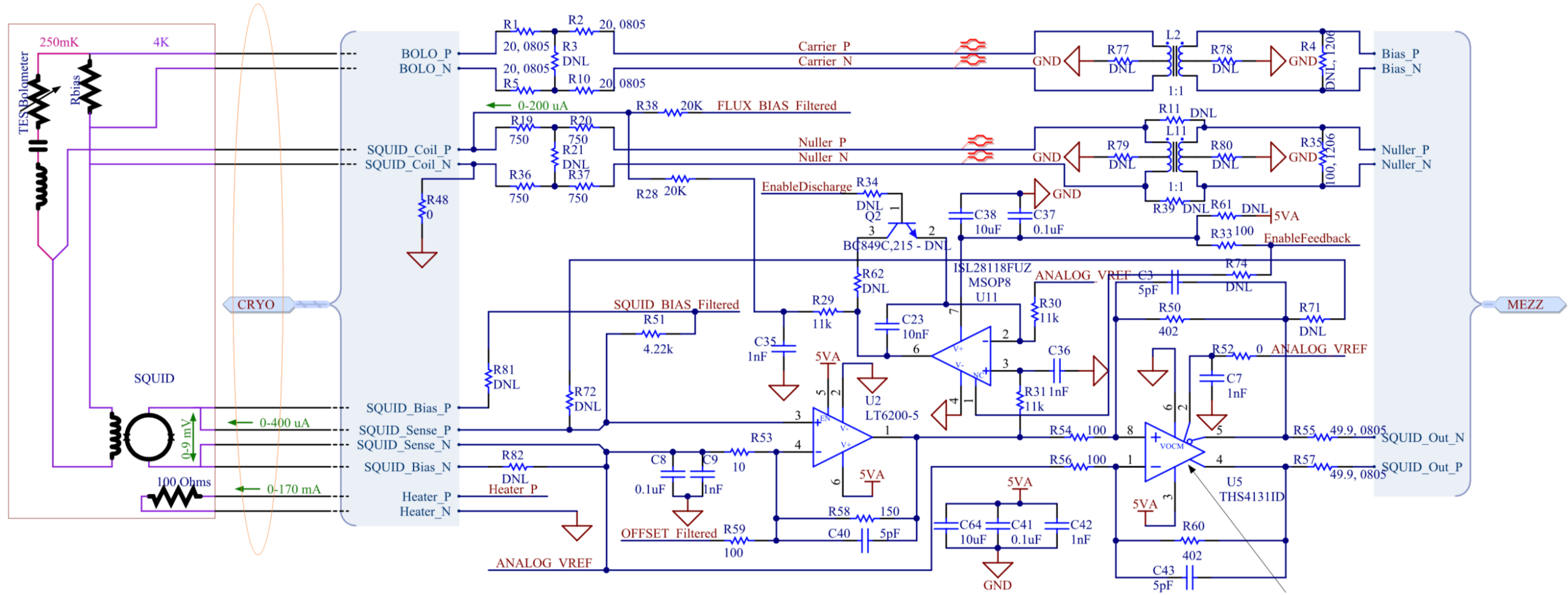
At present we are putting a total of around 7 or 8 STP litres of ^3He into these devices. With luck a redesigned version will need a bit less.

They are currently priced at around £64K Sterling inclusive of the gas, and around £46.5K Sterling ex.gas.

Best regards,
Simon.



BIAS and NULLER PASSTHROUGH



(MGNGSQ4, but equivalent to STDP SCU)