Ground “Low Frequency” Feasibility Study

Cryogenics

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Overview

- Cryo technologies for CMB ground-based experiments
- Summary of present most widely used cryo-solutions
- Developments of possible future technologies
- Outline of a possible study for cryogenic systems future developments for CMB ground-based experiments

Cryo technologies for CMB ground-based experiments

Cryogenic **tech** is used in (ground-based) CMB experiment for:

- detectors/focal planes/optical units cooling (both direct or as precooling)
- cryostats
- temperature control stages

Cryogenic **devices** are:

- **Active**
  - Refrigerators
  - Heat switches
  - Active control loops
- **Passive**
  - Liquid storage
  - Thermal Straps
  - Heat Switches
  - MLI/SLI and rad control shielding
  - Thermometry

These sub-systems integrate in a system called **cryostat** aimed to insulate (conductively, radiatively, convectively) the cold units from environment

CMB experiments temperature scale

- Refrigerator working principles is defined by final **Operating T needs**
- Op T depends on **detectors/optics technologies** used
- In the past "**low frequencies**" were typically observed from ground → **coherent detectors**
  - Coherent detectors (radiometers, polarimeters) technology typically requires 4 – 20K range → to date target T is around **20K**
- Recently CMB observatories operating into a limited amount of "**high frequencies**" range have been successfully implemented AND the potential extension of **bolometric detectors** to lower frequencies
  - Bolometers-type require lower temperature (and more complex technologies): **0.3 – 0.1 K** (or below)

Ground CMB exp's cryo solutions: today 1/2

Today CMB ground experiments are in general based on the following techs

- Cooling **above 1K**
  - **100 - 4 K** range, dedicated to **coherent** HEMT-based receivers:
    - mechanical cryocoolers (off-the-shelf)
      - Pulse Tubes, in particular for the 15 - 30 K range, GM, Stirling
    - LN2/LHe (custom designs by scientific teams w/ industry support in some cases)
  - **2 - 4 K** range, typically used as **pre-coolers** for sub-K refrigerators:
    - Pulse Tubes (off-the-shelf)
    - LHeI/II (custom designs by scientific teams w/ industry support in some cases)
- Cooling **below 1K**
  - ^{3}He or ^{3}He/^{4}He **sorption** coolers (typically custom made by scientific teams)
  - **dilution** refri (custom designed by scientific teams but availability on the market in rapid growth)

Ground CMB exp's cryo solutions: today 2/2

- Temperature **control** stages
  - PID based control loops (thermistor/heater couples)
- Heat **switches**
  - active gas systems (gas depending on T)
- **High conductance** links:
  - Cu straps
- **Low conductance** struts:
  - GFRP, Kevlar, SS, CFRP

Ground CMB exp's cryo solutions: tomorrow 1/3

Potential **key** technologies/expertise for **next** CMB ground experiments

- Present ground based experiment cryo-systems **design** is based on:
  - Large budgets (power, mass, volume)
  - Assumption of large margins
  - Margin on margin → **overdesign**
- Increasing performance demand (size of focal planes grows year by year) will lead to available **budgets reduction**, will become the limit to future experiments size
- Cryo/thermal **system engineering** will be the key to **optimized** future instruments

Ground CMB exp's cryo solutions: tomorrow 2/3

Potential **key** technologies/expertise for **next** CMB ground experiments

- Cooling **above 1K**
  - **100 - 4 K** range, dedicated to **coherent** HEMT-based receivers:
    - Optimized mechanical cryocoolers (industrial research)
      - Vibration control, efficiency (cooling power vs input power)
    - H_2 sorption JT, Ne sorption JT (research teams)
  - **2 - 4 K** range, typically used as **pre-coolers** for sub-K refrigerators:
    - Optimized Pulse Tubes (industrial research)
    - 2K ^{3}He JT, 4K ^{4}He JT (research teams)
- Cooling **below 1K**
  - Optimized ^{3}He or ^{3}He/^{4}He **sorption** coolers (research teams)
    - Minimum T, duration, heat lift
  - **Dilution** refrigeration (either off-the-shelf or custom made)
    - CC recent results, aimed to dedicated space applications, demonstrate the capabilities of motivated scientific teams working closely with industrial partners

Ground CMB exp's cryo solutions: tomorrow 3/3

- Temperature **control** stages
  - Passive design (RC damping)
  - New logics (fuzzy logic, swarm intelligence PID autotuning)
- Heat **switches**
  - Optimized active gas systems
  - Shape memory material
- **High conductance** links:
  - Straps: Cu, Al purity and efficiency of braids
  - Carbon based nanomaterials (graphene)
- **Low conductance** struts:
  - CFRP (fibers orientation) below 50K
  - Polymers (Peek)
  - Polimides (Vespel) below 10K
  - Ceramics (Macor, Alumina) below 10K

Feasibility study for the next CMB ground cryo-systems

Design & development of all listed technologies will require **dedicated** technology development **projects** (involving industry)

Activities that, if of any **interest** and **properly supported** by projects, could be carried out to lay out a possible path for the design and development of future cryo-systems for the next generation CMB ground based experiment:

- Identify the **needs** (requirements) for next generation CMB ground experiments
  - Operating temperature, heat lift, T stability, vibration level
- Identify the (most promising) **key technologies** to be developed (in Italy?)
- Evaluate and propose a **roadmap** for their tech development in the national and international scenario
- Analyze required **budgets**, **critical issues** and **interfaces** (not only thermal/cryo)
- Propose optimized architectures for CMB ground observation **cryostats**, for example:
  - A baseline for coherent receivers
  - A baseline for bolometric detectors