Cooling

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Towards the European Coordination of the CMB programme
Villa Finaly, Firenze, 6th -8th Septemeber, 2017

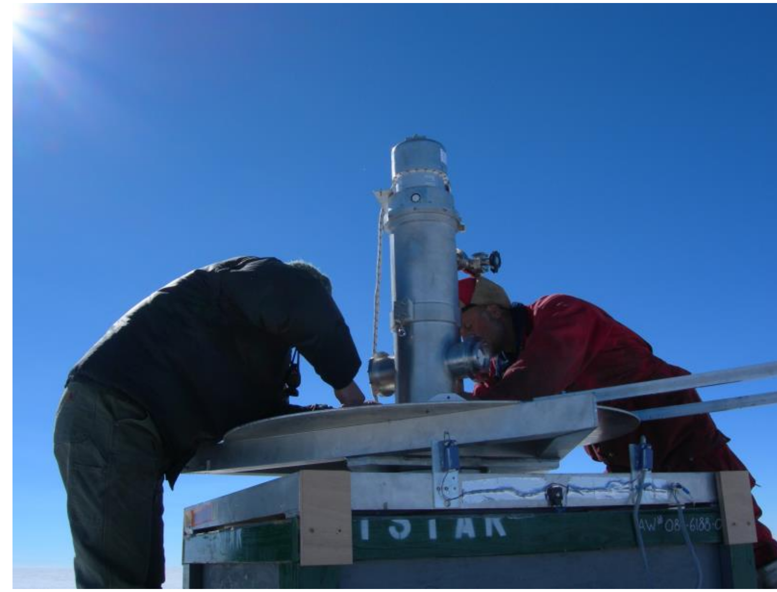
https://indico.in2p3.fr/event/14661/

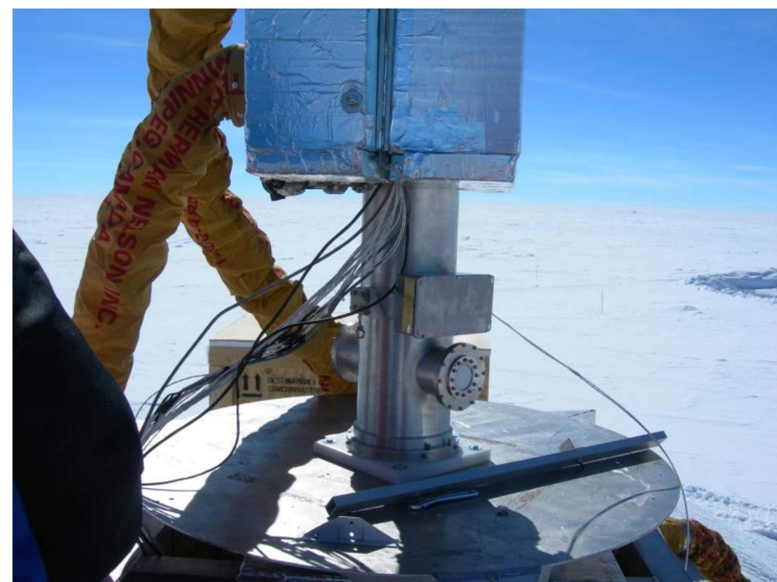
Cooling for CMB experiments

- Ground-based observations of the CMB are carried-out from high-altitude, cold, dry sites. The instruments require complex cryogenic systems to cool down the optical chain and the detectors.
- Custom-developed, rugged cryogenics must be used, able to operate for long periods, possibly without any maintenance, under automated/remote control.
- The cryo-system cools a large volume (order $1 m^3$) inside the cryostat with two main stages, one at about 40 K and the other at about 3 K. Must withstand the **optical load from a large entrance window**, needed due to the large throughput of current CMB polarimeters.
- The typical heat lift needed at **40K** is of **10-20W** depending on the size of the window and the efficiency of the thermal filters chain.
- The typical heat lift needed at **3K** is around **1W**, to **cool down the optics (including polarization modulators), the filters chain, the cryogenic amplifiers of the detection chain**.
- A lower operating temperature stage is added by using ^3He evaporation refrigerators (**0.3 K**) or dilution/ADR fridges (**0.1 K**) with a heat lift of the order of **1-30 μW** to **cool the focal plane and the detectors**.

Dry Cryostats

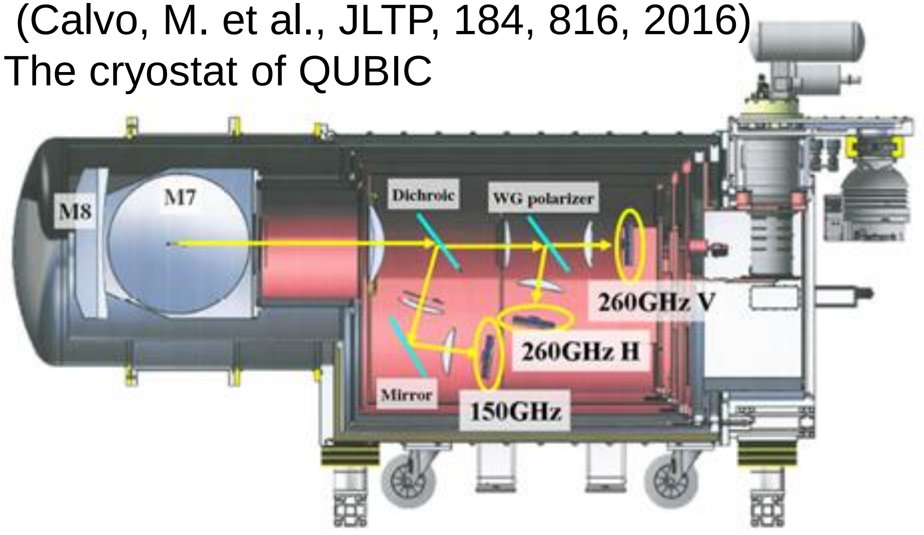
- **Pulse-tube cryocoolers** are optimal to the purposes above, since
  - They produce the required heat lifts
  - They do not require filling of cryogenic liquids, whose delivery at remote sites can be difficult
  - Produce a low level of vibrations (not zero, however)
  - Operate continuosly and reliably, with a mean time between servicing of the order of 10000h.
  - Have a reasonable efficiency.
- However, they set **logistic requirements**:
  - Each pulse tube has a compressor.
  - This requires typically10kW of electrical power. If this is produced by a generator (as in Dome-C), a lot of fuel is needed every year to operate it:
    - Generator efficiency 3 kWh/liter
    - 30000 liters of diesel per year for each pulse tube
    - 25 tons of fuel to deliver at the site and stored
  - Has to be cooled. Either running water (5 l/m) or a chiller using cold air and a transfer fluid in a radiator (glycole for the low temperature sites of interest here).
- **These logistic problems should be properly accounted for in the first design of the experiment and in the selection of the site.**
- It is not impossible, even in ultra-remote sites: we operated succesfully a ^{3}He fridge with a pulse tube cooler in Dome-C already in 2005-2006 with the BRAIN experiment (Polenta et al., New Astronomy Reviews, 51, 256–259, 2007).

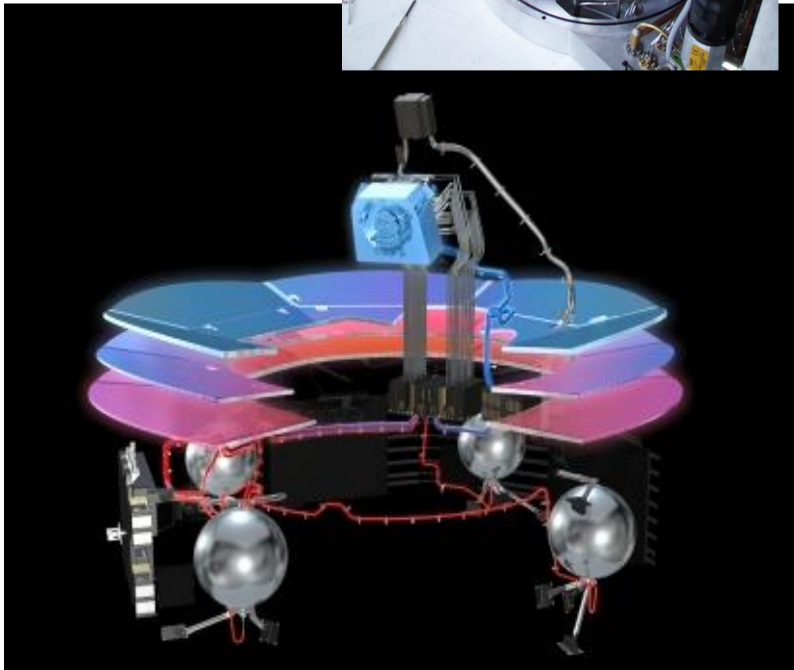




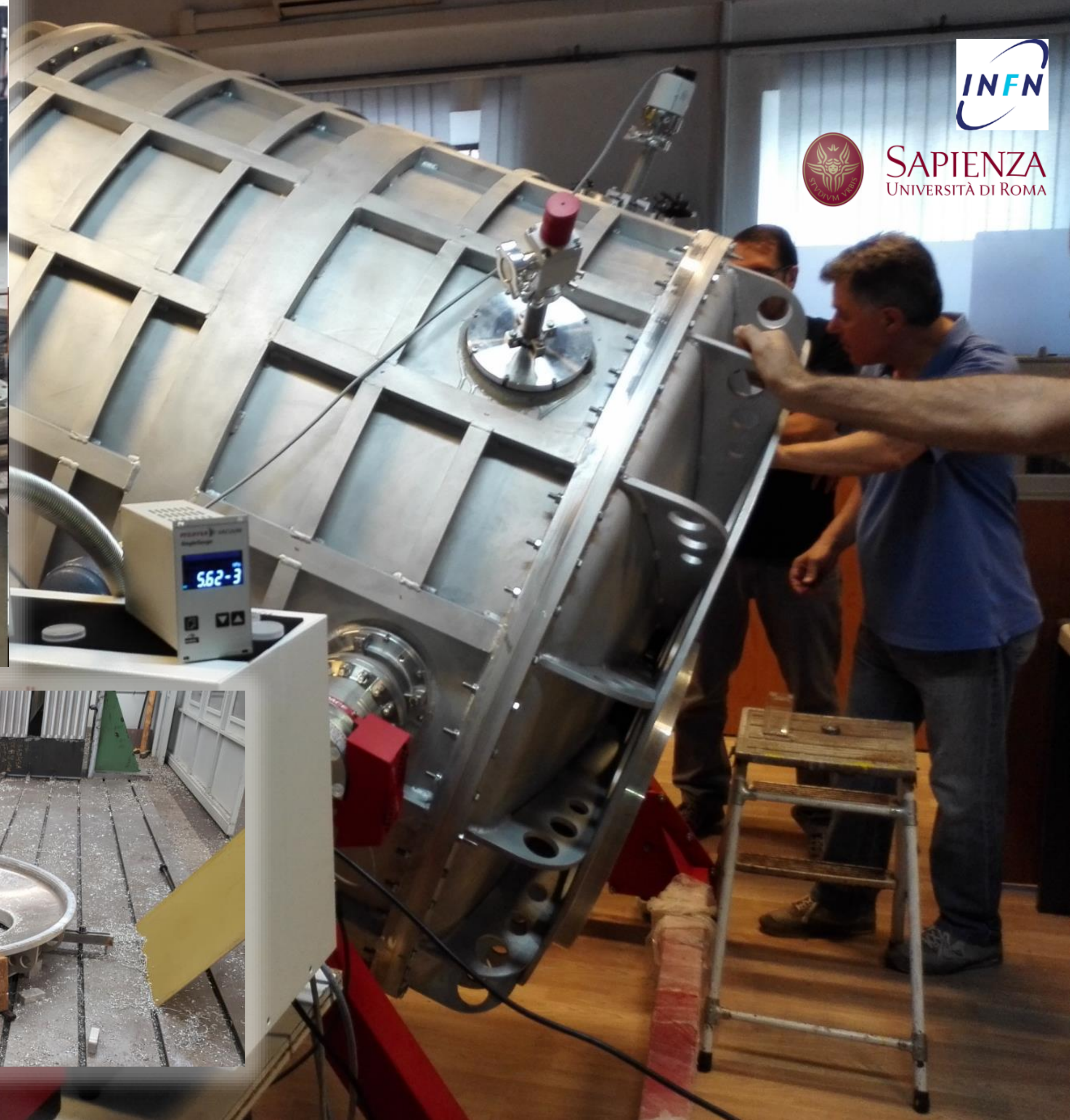
Experience in Europe

- Europe is strong in cryogenics for CMB & experiments.
- Sample cryogenic systems for CMB experiments.
- Balloons:
    - Pronaos (Beaudin G et al Proc. SPIE Vol. 1874, p. 246-255)
    - BOOMERanG (S. Masi et al. "*A self contained 3He refrigerator suitable for long duration balloon experiments*", Cryogenics, 38, 319-324, 1998 and S. Masi et al., "*A long duration cryostat suitable for balloon borne photometry", Cryogenics*, 39, 217-224, 1999.)
    - ARCHEOPS: precursor of the Planck dilution fridge (A. Benoit and S.Pujol. Cryogenics 34, 421, 1994)
    - PILOT (Bernard, JP., Ade, P., André, Y. et al. Exp. Astron., 2016, 42)
- Satellites:
    - Planck: An innovative dilution fridge (0.1K) has been developed for Planck (S. Triqueneaux, L. Sentis, P. Camus, A. Benoit, and G. Guyot. *Design and performance of the dilution cooler system for the Planck mission*. Cryogenics, 46(4):288–297, 2006.)
- More specifically, PT-based systems for ground-based experiments:
- The NIKA2 instrument at IRAM Pico Veleta (Calvo, M. et al., JLTP, 184, 816, 2016)
- The cryostat of QUBIC





QUBIC cryogenic system



Cooling the focal plane

- Final temperature to operate detectors depends on:
  - Radiative background on the detectors i.e. selected bands, quality of the atmosphere, spillover level, quality of filters stack
  - For TESs with a given transition temperature, a lower base temperature enchances the saturation power, i.e. the dynamic range of the measurement
  - For KIDs, a temperature << than the binding energy of Cooper pairs (i.e. cut-on frequency) is required
- 0.3K can be achieved with a simple ^{3}He evaporator. Very nice fridges with 1K buffer and with double ^{3}He stage are available in many labs and even commercially in Europe.
- 0.1K coolers improve the performance, adding significant complexity and with lower cooling power. *ça va sans dire*: Grenoble excellence with dilution coolers.
- The increasing cost of ^{3}He (3000€/lSTP) is an issue in both cases. Otherwise, these systems are extremely reliable and well experimented.
- It is also possible to reach the 0.1K range, starting from 0.3K, on the detector chip. Example from prof. Kuzmin below:

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Realization of Cold-Electron Bolometers with Ultimate Sensitivity due to Strong Electron Self-Cooling

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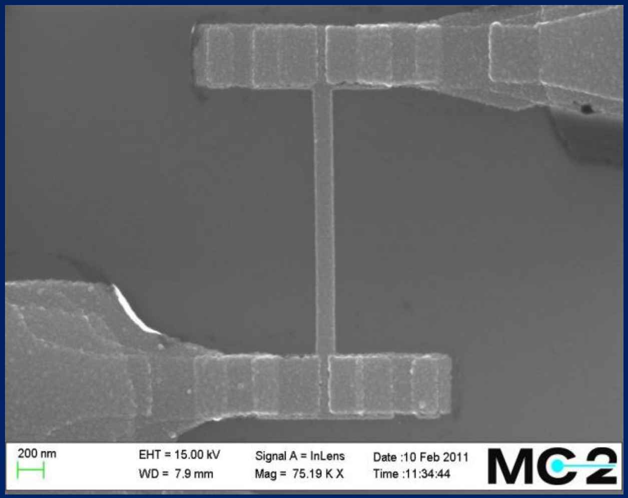
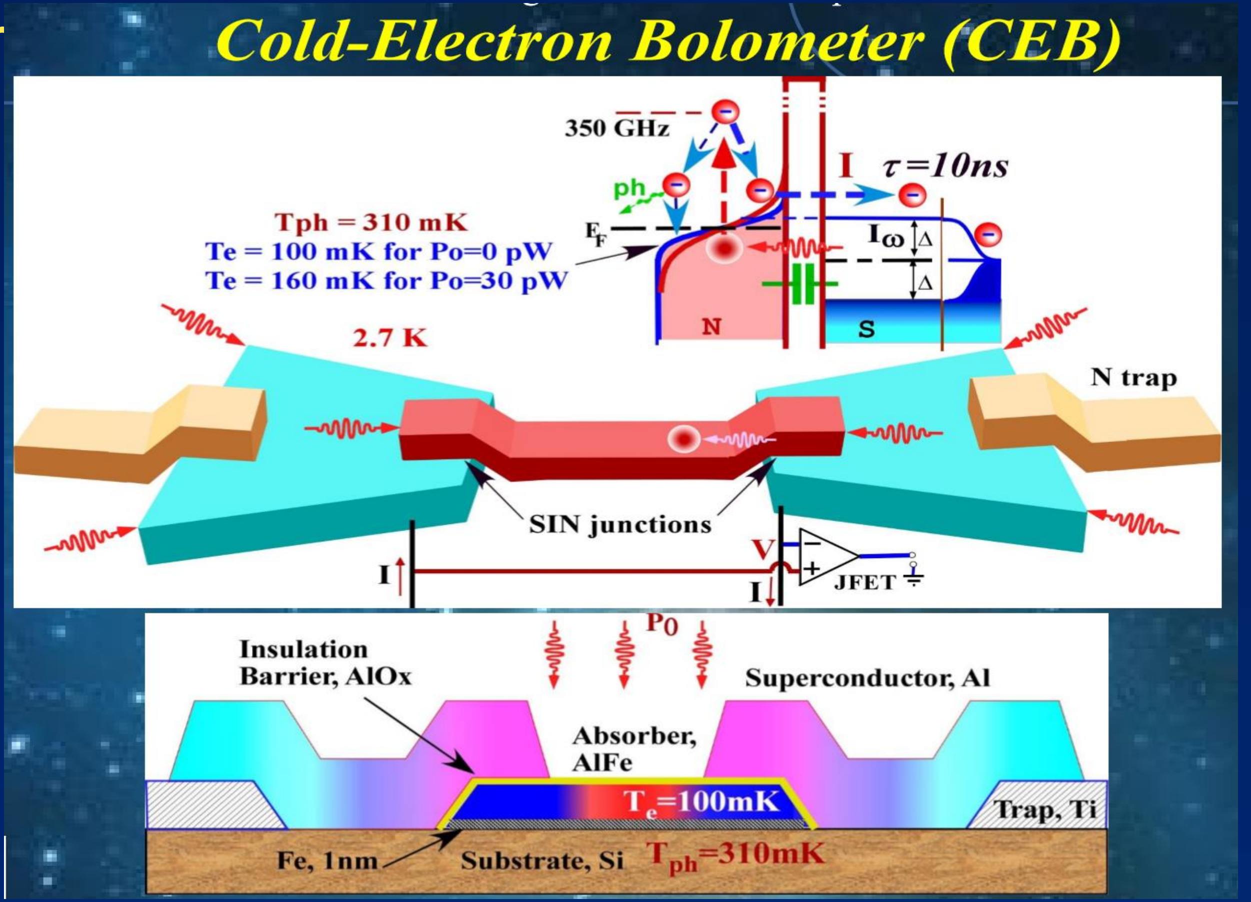
Cold-Electron Bolometer





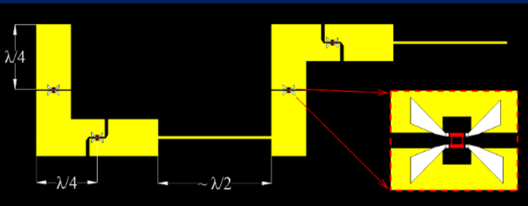
<u>Main features of the CEB:</u>

1. High sensitivity, and on-chip electron cooling.

Photon noise limit could be achieved with a base temperature of 300 mK

2. Insensitivity to Cosmic Rays

Experiment in Chalmers

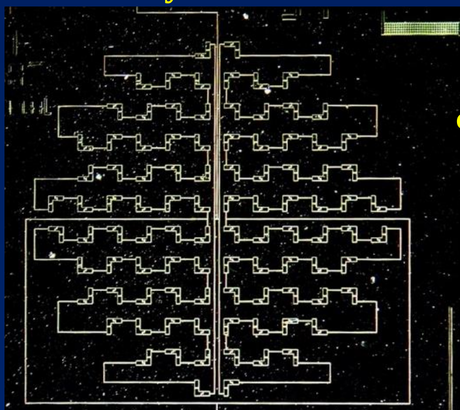


Single element: 2 orthogonal dipoles with CEB inside for two polarizations

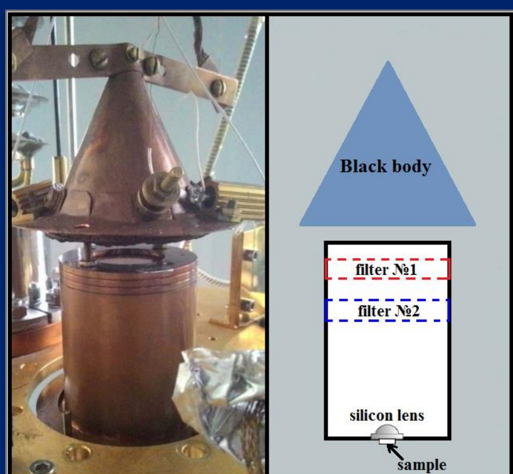
NEP components and NEPph:

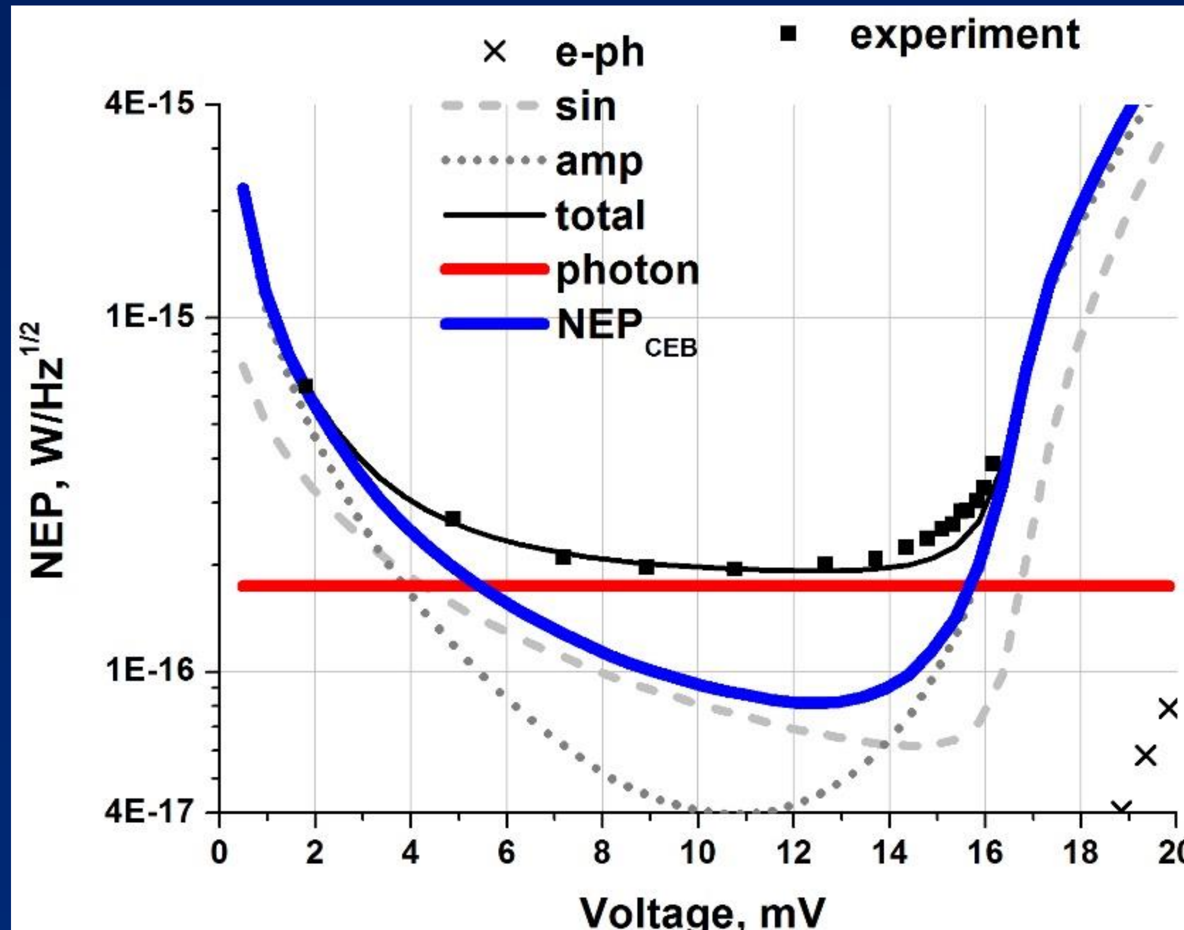
Po=30 pW **.NEP_{CEB} <NEP_{PH}**

2D array of 4x46 CEBs



23 pixel system compatible with OLIMPO





- Strong Electron Self-Cooling in CEBs demonstrated, from 300 to 70 mK (no power load)
- Ultimate Photon-Noise-Limited CEB due to on-chip Electron Self-Cooling from 330 to 170 mK under 30 pW background load.
- For this detector technology, this effect simplifies significantly the cryo system.