The CMB from A to Z: Promises and challenges of the CMB as cosmological probe
Nov 13 - 17, 2017

CMB instruments 2/3

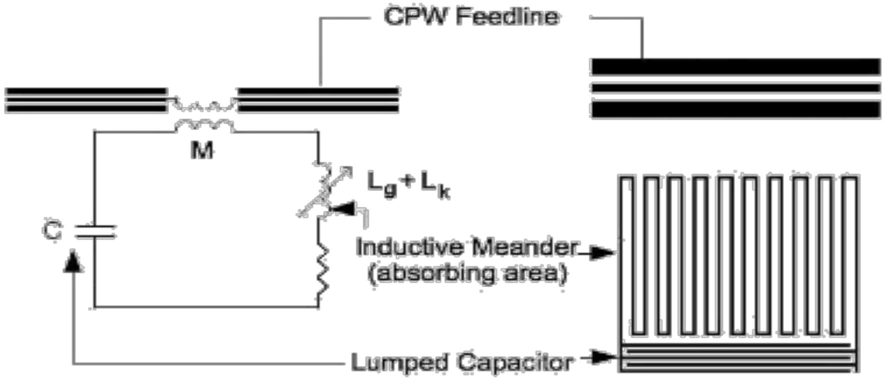
Michel Piat
piat@apc.univ-paris7.fr

Designing a CMB experiment

1. CMB photons
2. CMB detectors
    - 2.1 Coherent detection techniques
    - 2.2 Incoherent detectors: TESs, **KIDs**
3. CMB instruments design

2.2 Coherent detection techniques: Kinetic Inductance Detectors (KIDs)

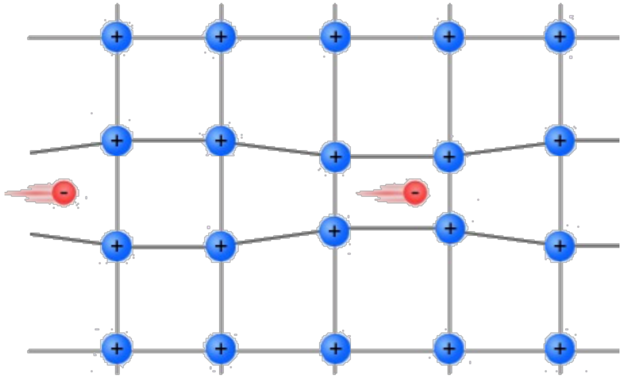
- Recent development: P. Day et al., Nature 2003
- Very fast developments
- Kinetic inductance
  variation of a superconducting
  absorber in a resonant circuit



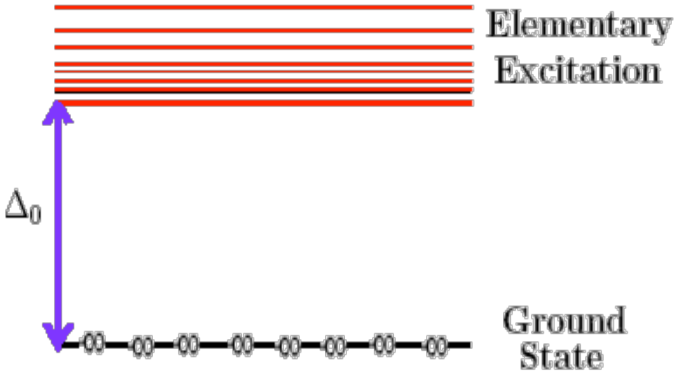
Some slides from Andrea Tartari (INFN Pisa) and Alessandro Monfardini (IN Grenoble)

Superconductivity: what happen below T_c?

- Microscopic theory: Bardeen-Cooper-Schrieffer (BCS)
  - Coulomb interaction between electrons: shielded by crystal lattice
  - Coupling of 2 electrons with energy close to the Fermi level by phonon exchange



- Results = boson = **"Cooper pair"**
  - Mass = $2m_e$
  - Charge = 2e
  - Binding energy: $2\Delta \approx 3.5 k_B T_c$
    2Δ(T) ~ fraction of meV (detector case)
  - Typical size (coherence length): #1µm (depends on material)
  - Dissipation less movement



(Andrea Tartari)

Kinetic inductance

- Cooper pairs:
  - ➢ Coherent movement due to E field
  - ➢ Without any collision
  - ➢ **High kinetic energy**
    - ✓ **Acts as an additional inductive term:**

$$U_k = \frac{1}{2}\int_V m_s n_s v^2 dV = \frac{1}{2} L_k I^2$$

  - ➢ In practice: $L_{tot} = L_{geo} + L_k$

(Andrea Tartari)

Kinetic Inductance Detectors

(Microwave Kinetic Inductance Detectors MKIDs)

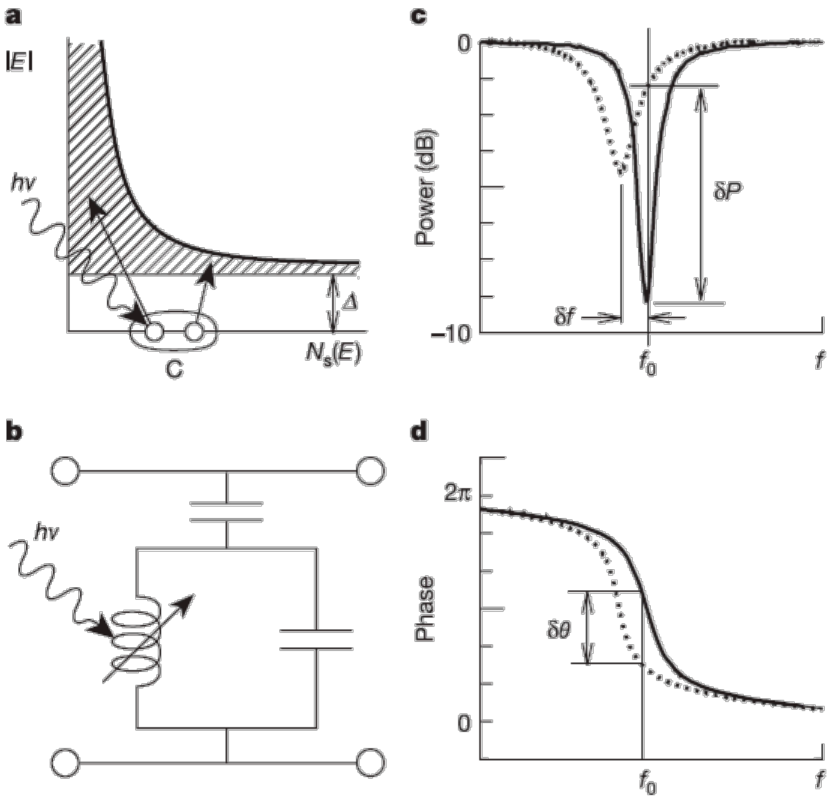
- LC resonant circuit

- Effect of photon absorption:
  - **If hν>2Δ**: Cooper pair breaking
  - Change of kinetic inductance and ohmic losses
  - **Change of resonance**
    - ✓ **Shift in resonant frequency:**

$$1/\sqrt{C(L_m+L_k)}$$

    - ✓ **Decrease of the quality factor**

- **Al KIDs:** $T_c \approx 1.1\mathrm{K}$ so $\nu > 100\mathrm{GHz}$
  - $T < T_c/10$

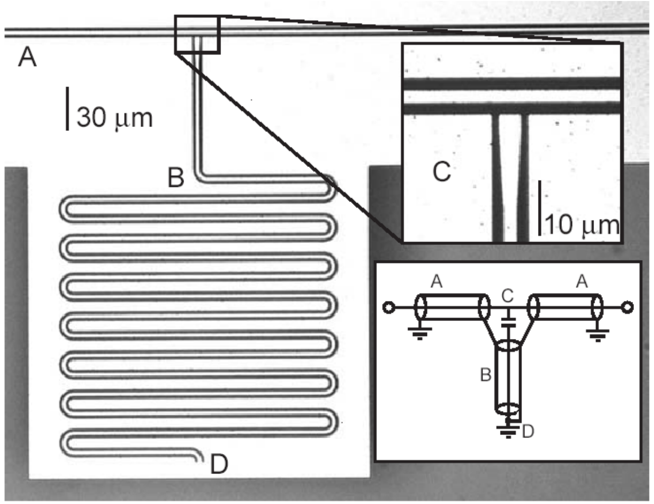


P.Day et al. Nature 2003

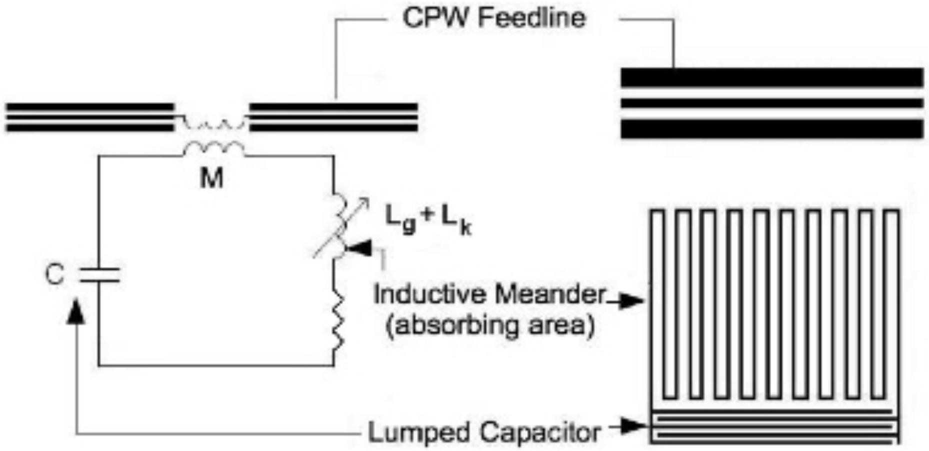
MKIDs: realisation of resonant circuit

- 2 solutions:

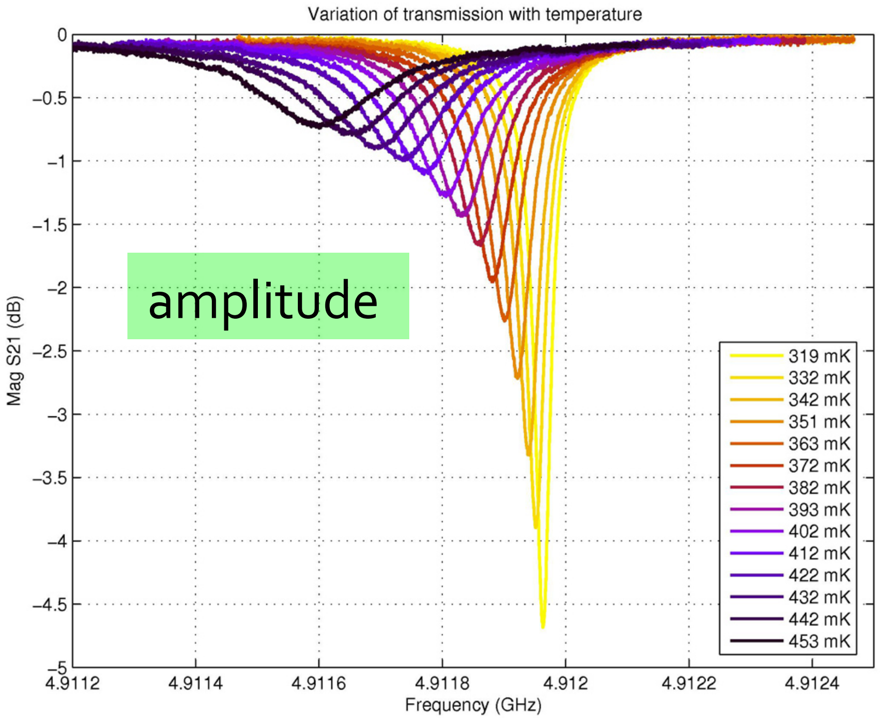
Short circuit at λ/4 (Mazin)

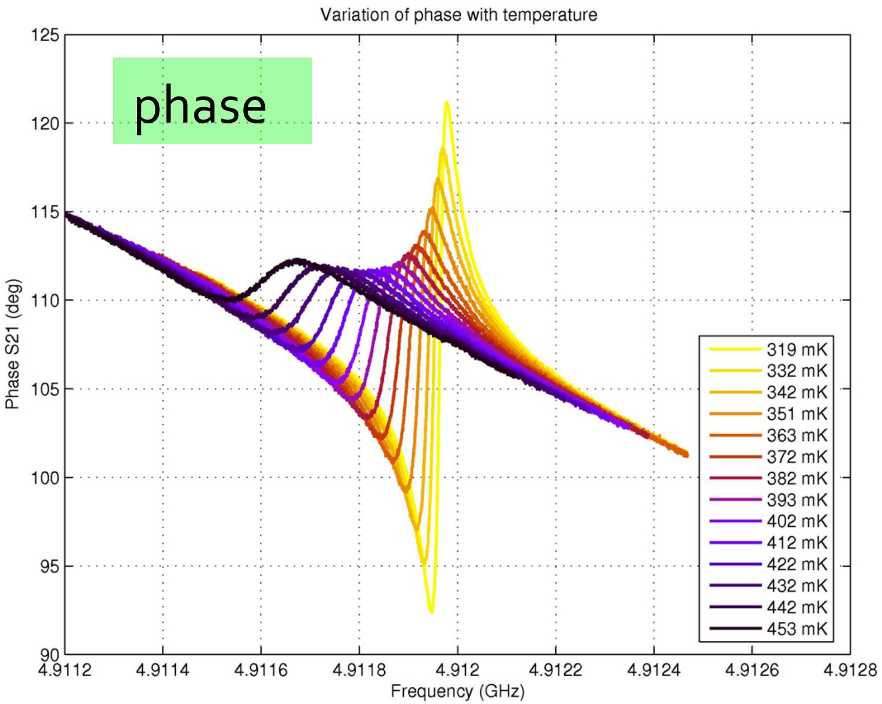


Lumped element (Doyle)



MKID resonance



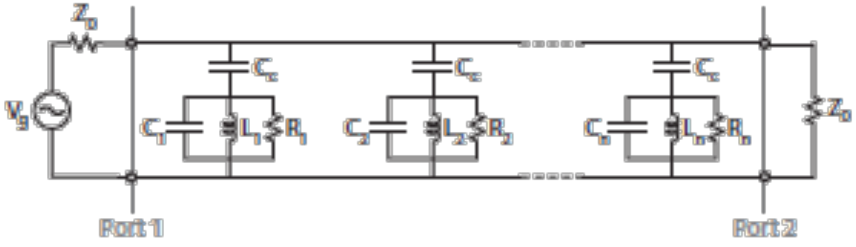


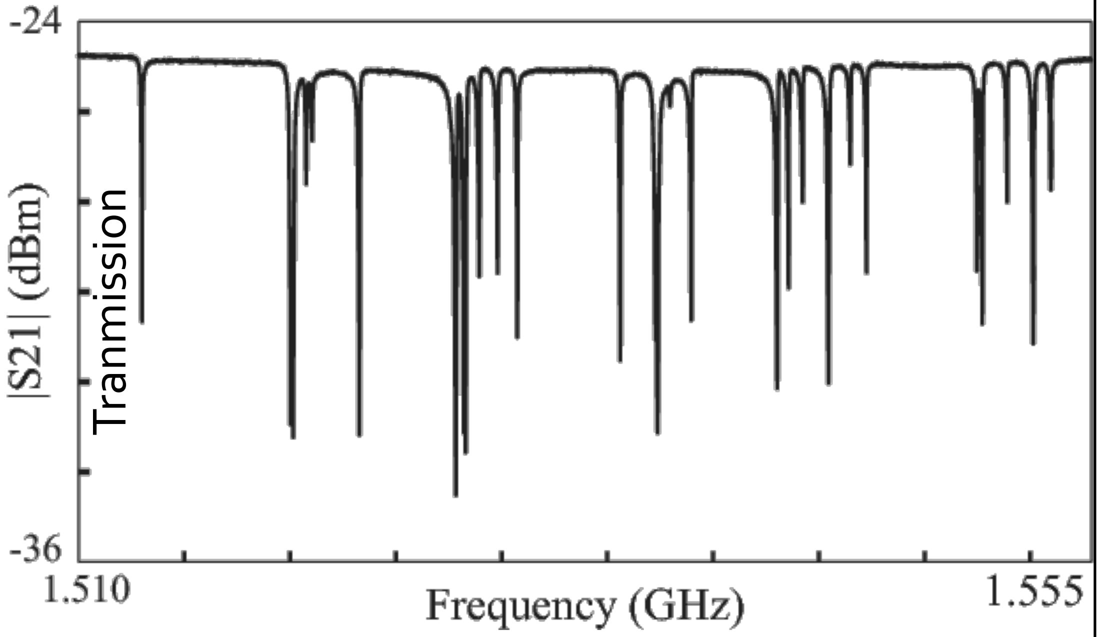
Higher T ➡ Higher n_{qp} ➡ Higher losses

Higher T ➡ Lower n_{cp} ➡ Lower f_o

MKID arrays

- Resonant frequency different for each detector
    - ➢ One single line to readout multiple detectors!

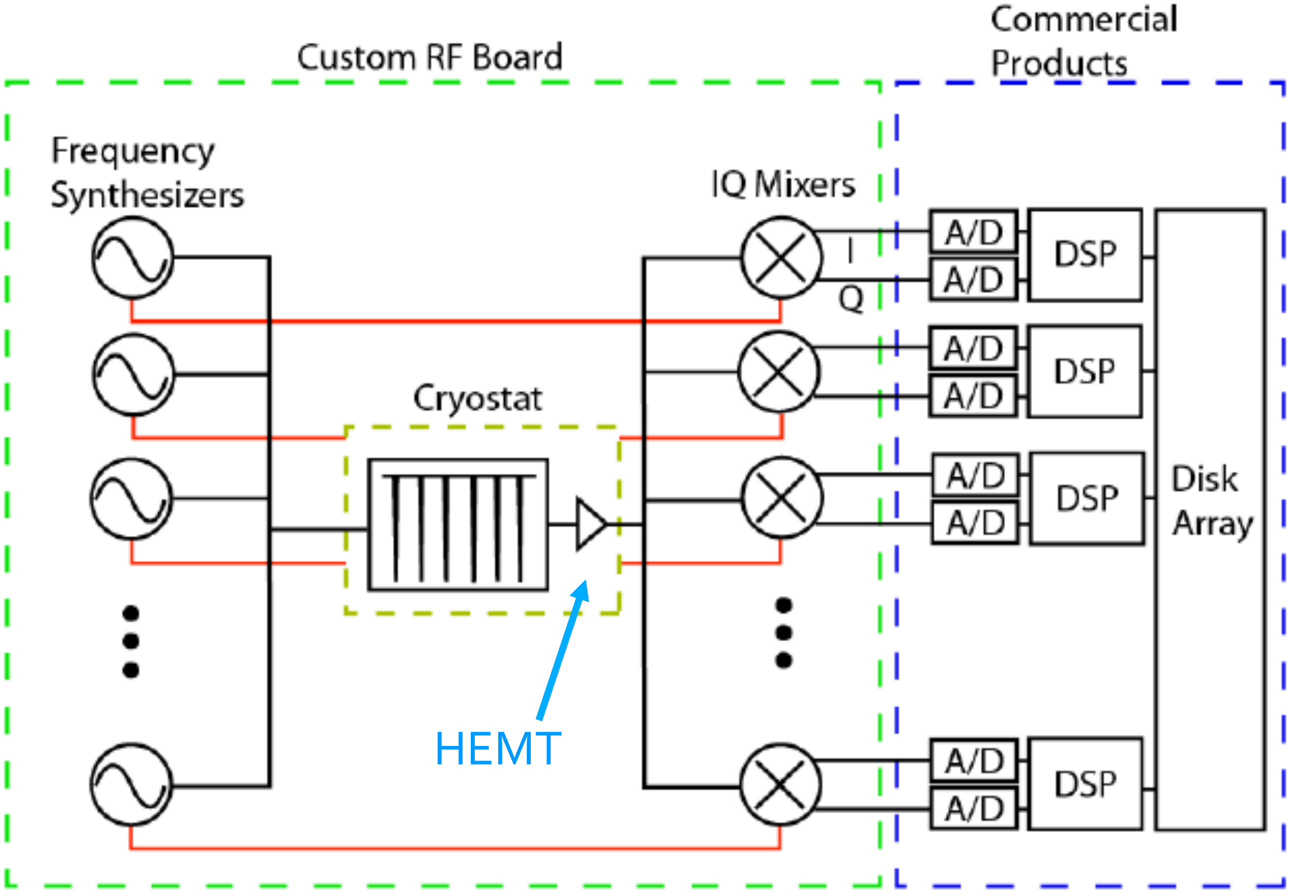




- ➢ **Intrinsically multiplexed in frequency**

MKIDs: readout system

- Excitation with multiple frequencies:



MKIDs noise

- **Generation-recombination noise** (GR):
  - ➢ fluctuations in the number density of quasiparticles (e-) from optical and thermal excitations
    - ✓ Low T required to reduce the number of quasiparticles (T<200mK) to reduce the thermal part
  - ➢ Optical part:

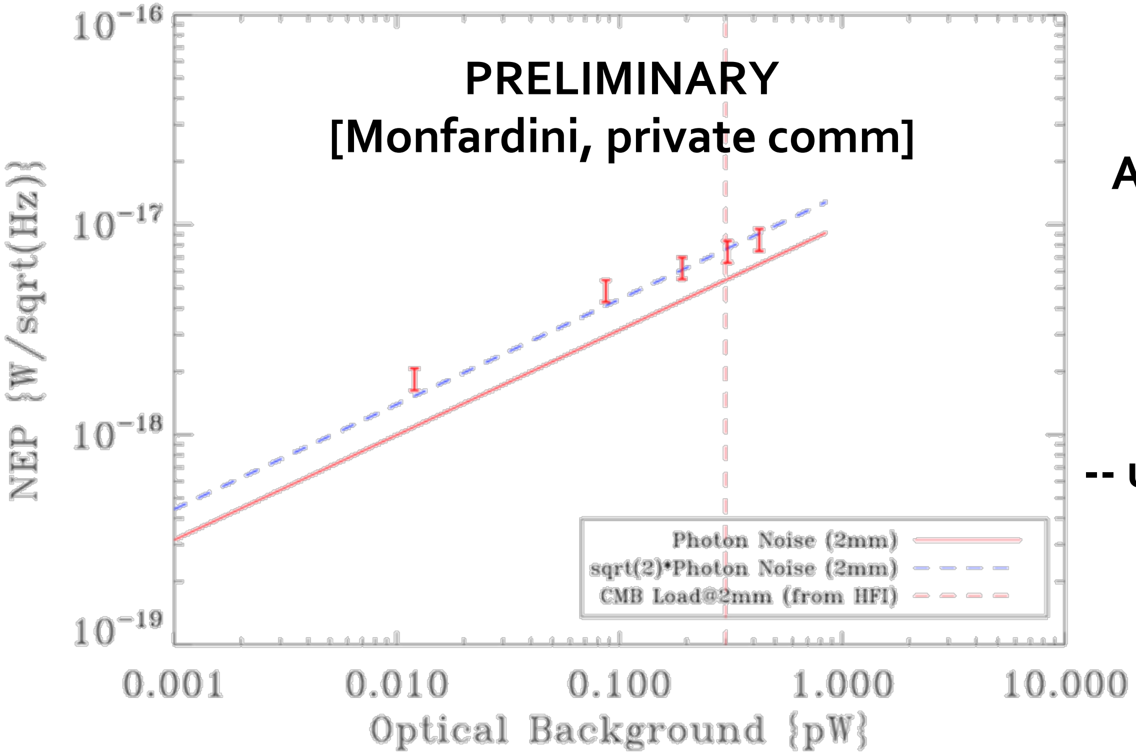
$$NEP_{GR}^{2} = \frac{2\Delta P}{\eta_{pb}}$$

[Yates et al., arXiv:1107.4330v1]

- ✓ η_{pb}: efficiency of converting energy into quasiparticles
  - ○ $\eta_{pb}=1$ for photon energy close to 2Δ
  - ○ Approach 0.57 for photon energy higher than 2Δ
- ✓ Depends on power background P

MKIDs noise

- R&D effort is making important progress:



PRELIMINARY
[Monfardini, private comm]

THE LOW-BACKGROUND
ARRAY AT 150GHz at 150mK

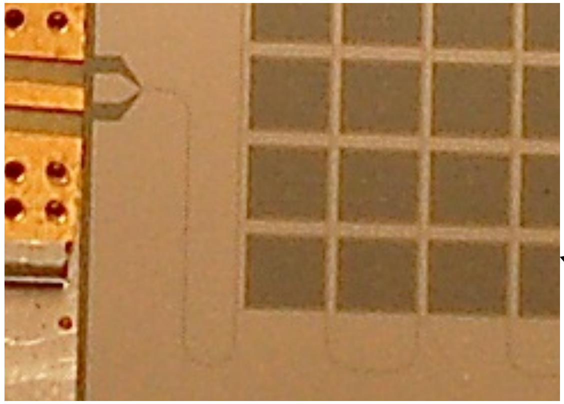
OPTICAL NEP !!!

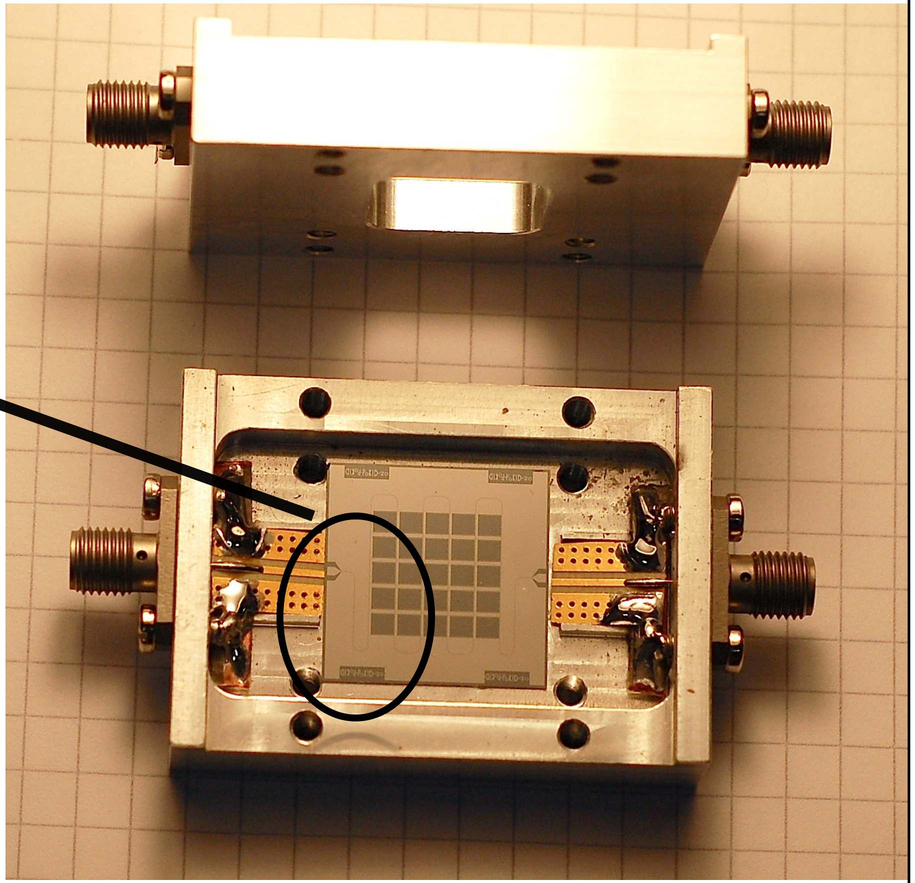
TAKEN AT 1-10 Hz
-- useful for real observations --

No fundamental limitation seen!

MKIDs: examples

- Aluminium MKIDs (T_c=1.1K)



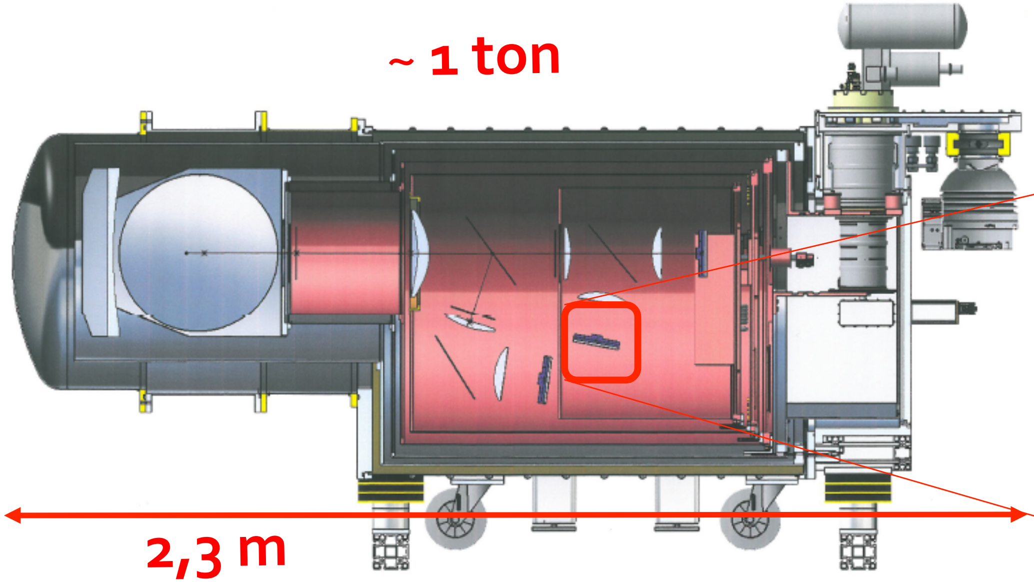


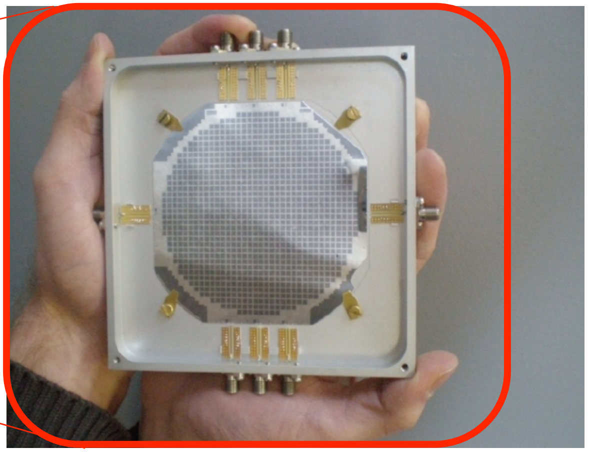
- NIKA instrument
  (*Néel IRAM KIDs Array*)
  - 132 pixels at 150 GHz at 100mK
  - 224 pixels at 240GHz at 100mK
  - IRAM 30m telescope
  - NEPs ≈ $8 \cdot 10^{-17}$ W/√Hz at 150GHz

NIKA 2 @ 30m IRAM telescope (Néel IRAM KIDs Array)

- 6.5 arc-min FoV (≡ IRAM 30m)
- Close to background-limited
- Dual-band imaging + polarization
- Derived from NIKA R&D

- **Dual-band (1.25mm and 2mm)**
- **Polarization @ 1.25mm**
- KID Arrays Detectors:
  - **1000 pixels @ 2mm**
  - **2 × 2000 pixels @ 1.25mm**
- NIKEL Read-Out Electronics

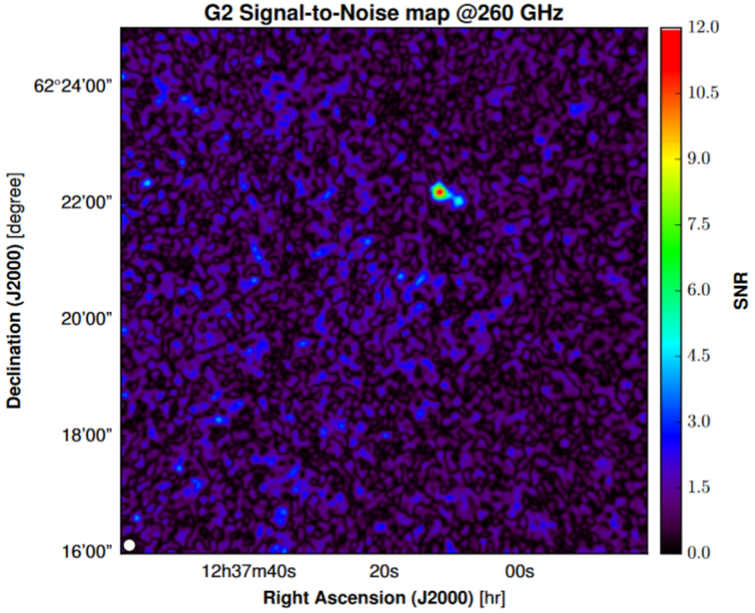




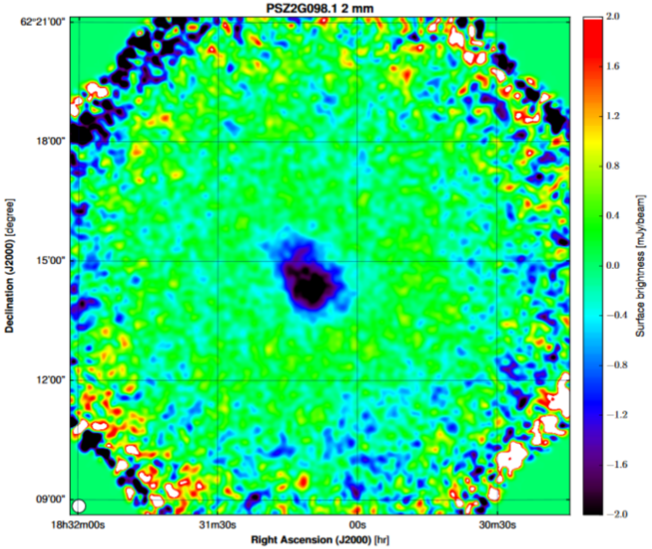
Alessandro Monfardini (IN)

Pictures from NIKA2 pool 1

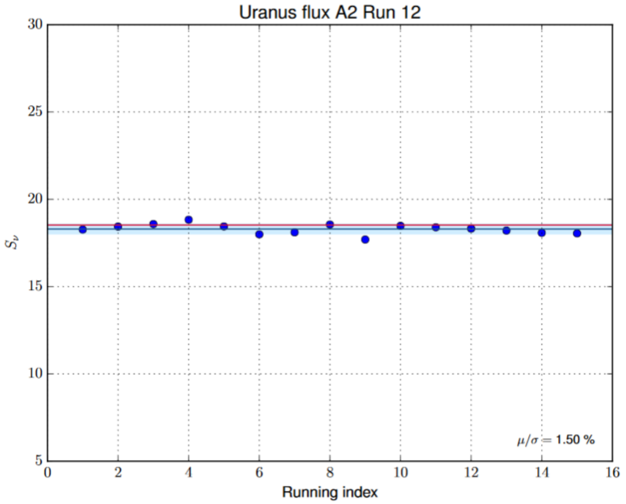
[Monfaridini, private comm]



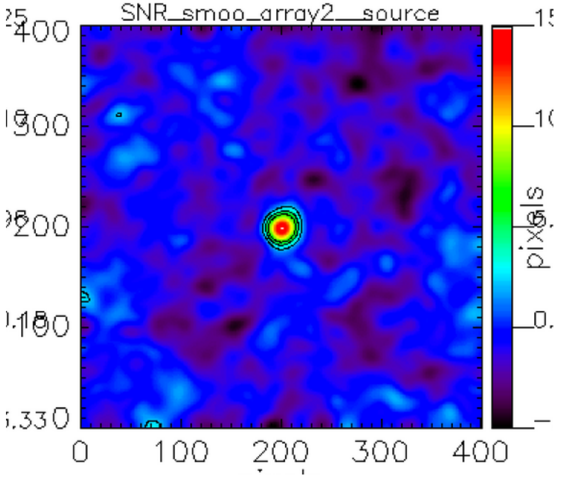
DEEP FIELD FROM NOEMA



A GALAXIES CLUSTER

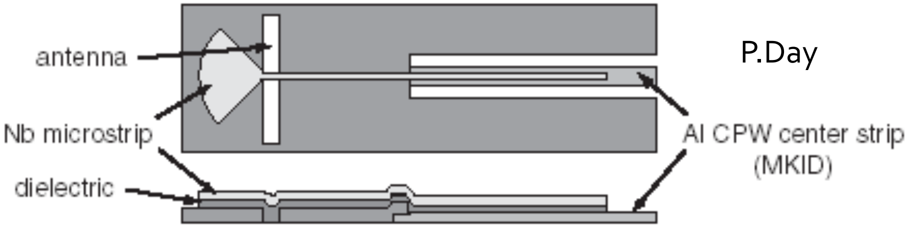


CALIBRATION STABILITY

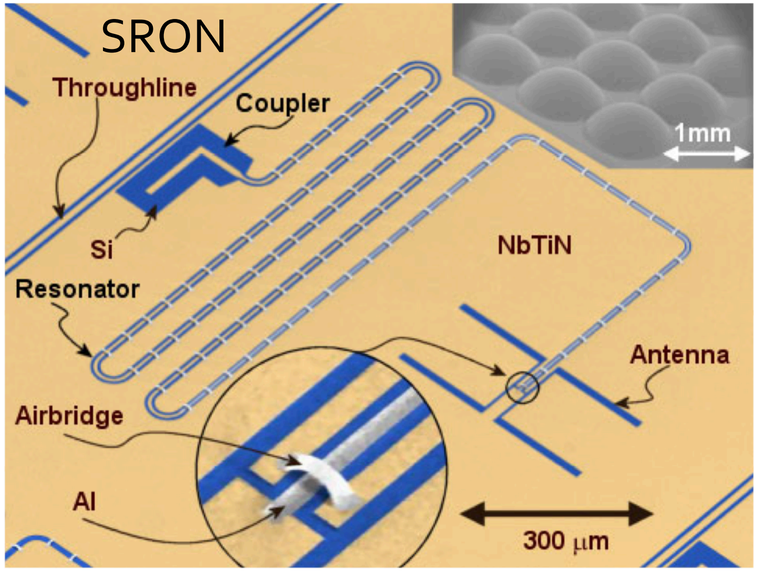


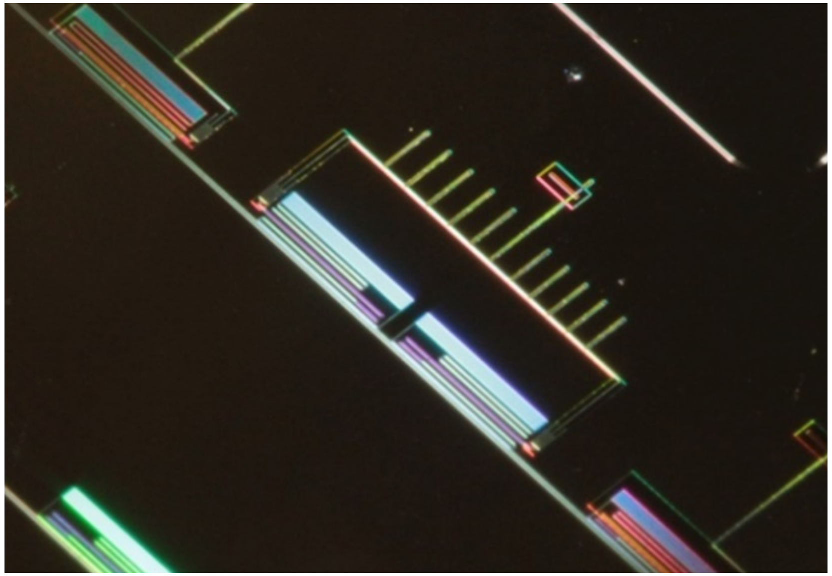
EXO-KUIPER BELT (HD107146)

Antenna coupled KIDs



P.Day

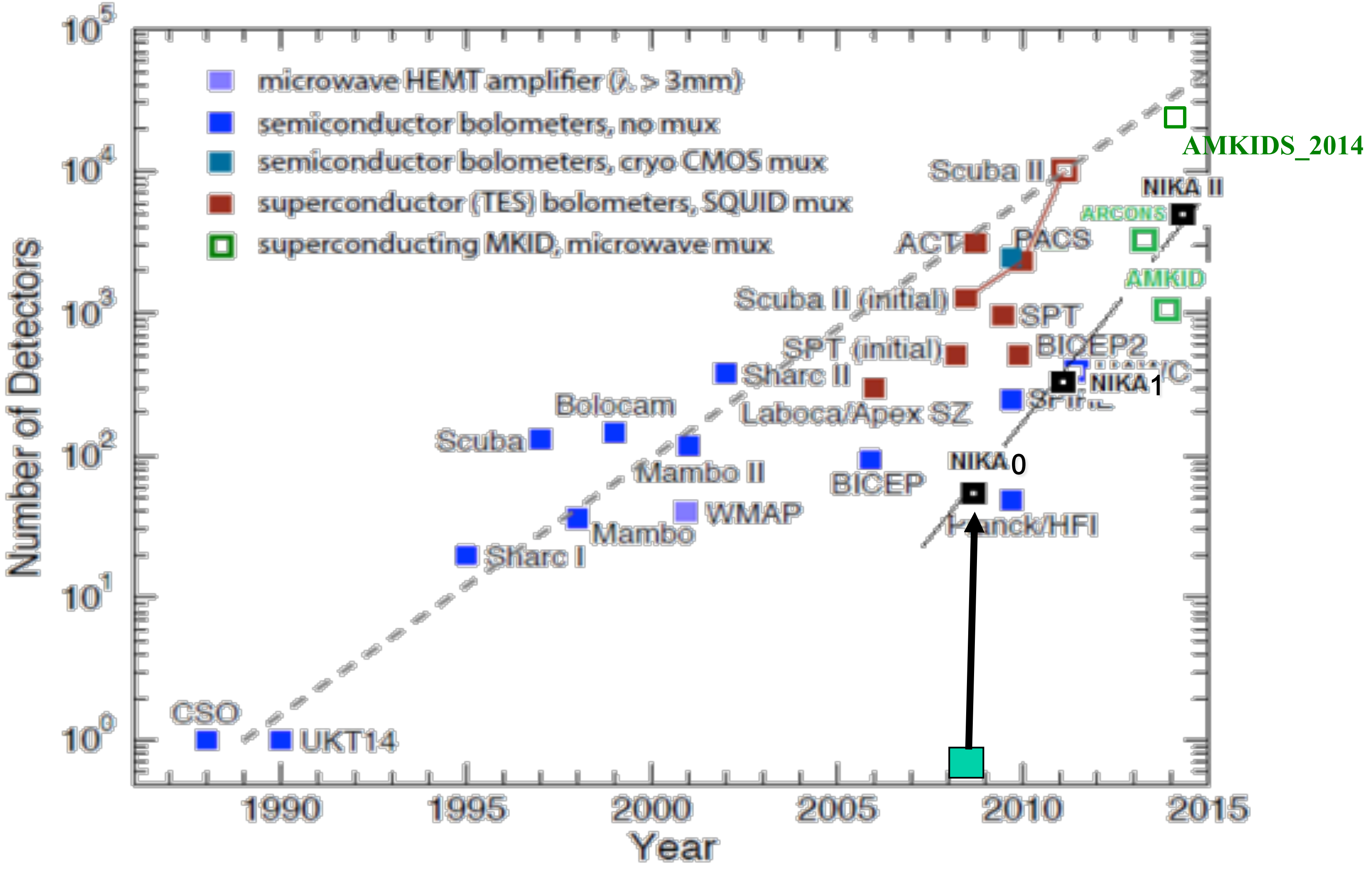




Efficiency still limited… R&D ongoing

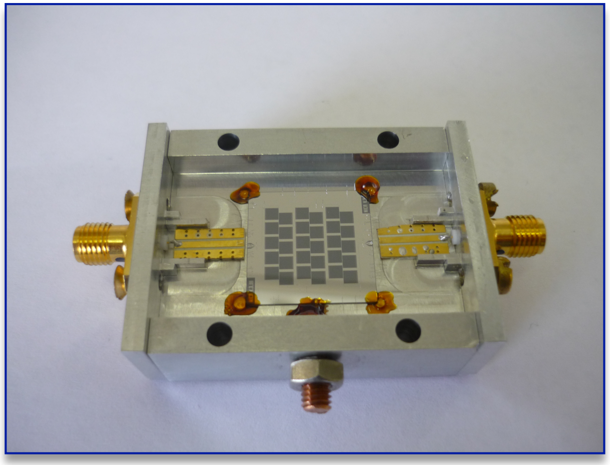
APC (Alessandro Traini)

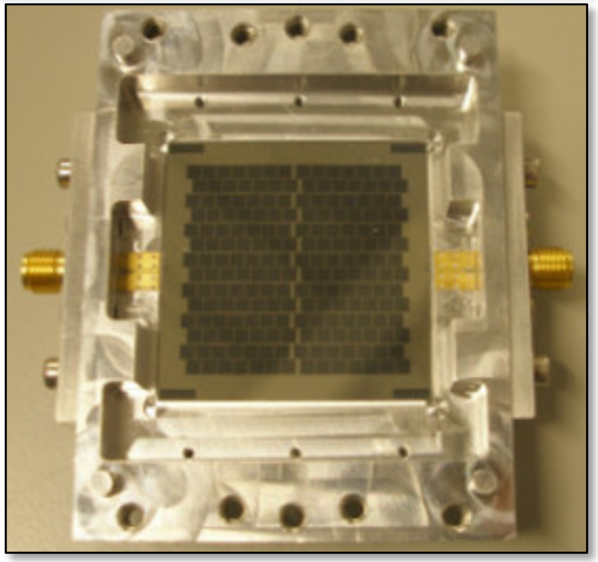
KIDs fast evolution



MKIDs: conclusions

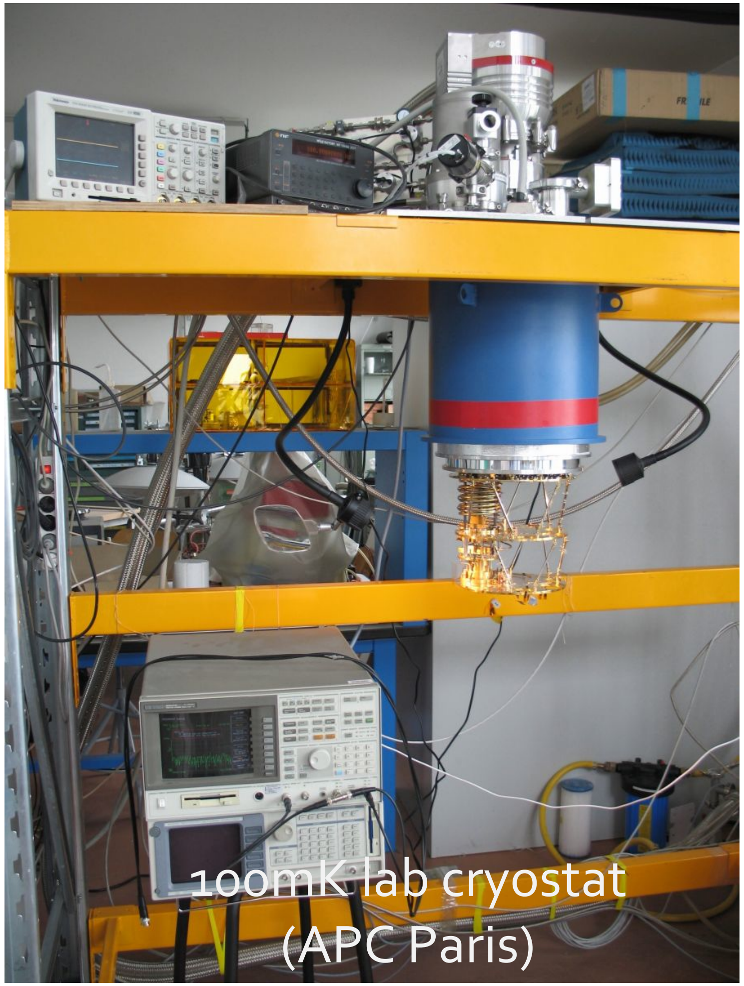
- Very promising detector
  - Very fast and active developments around the world
- Advantages:
  - Easier to manufacture than TESs
  - Multiplexing easier than TESs
  - Faster than TESs
- Difficulties:
  - Lower TRL wrt TES
  - No real full polarimeter up to now
  - No sensitivity below ~110GHz (Al KIDs)
  - Readout power consumption





System aspects

- Detectors sensitivity ~ 10^{-17}W to 10^{-18}W
- Instrumental design
  - Risk of sensitivity degradation
- The whole system has to be designed carefully!
  - System approach
  - Detectors to be tested with their subsystems in realistic conditions



100mK lab cryostat (APC Paris)

Detectors trade-offs

Color code: 🟩 Meet specs 🟧 Limitation 🟥 Critical

	TESs	KIDs
Sensitivity	🟩	🟧 R&D
Frequency range	🟩	🟧 Limited by energy gap
Time constant	🟧 ms range	🟩 Fraction of ms
Multiplexing	🟧 Complex at cold T	🟩 Natural
Fabrication complexity	🟥 10's process steps	🟩 Few steps
Sensitivity to Cosmic Rays	🟧 Balistic phonons	🟧 R&D
Power consumption	🟩 Low freq. electronics	🟧 Engineering
Pol sensitivity	🟩 Antenna coupled	🟧 R&D
Sensitivity to δT	🟧 Bath temperature	🟩
Sensitivity to B	🟧 Readout (SQUIDs)	🟧 Intrinsic sensitivity
TRL	🟩 TESs: 5-6	🟧 3-4