TEST and CALIBRATION

SAPIENZA
UNIVERSITÀ DI ROMA

E.S. Battistelli "Sapienza" University of Rome

OUTLINE

- Calibration starts before…at the detectors design level

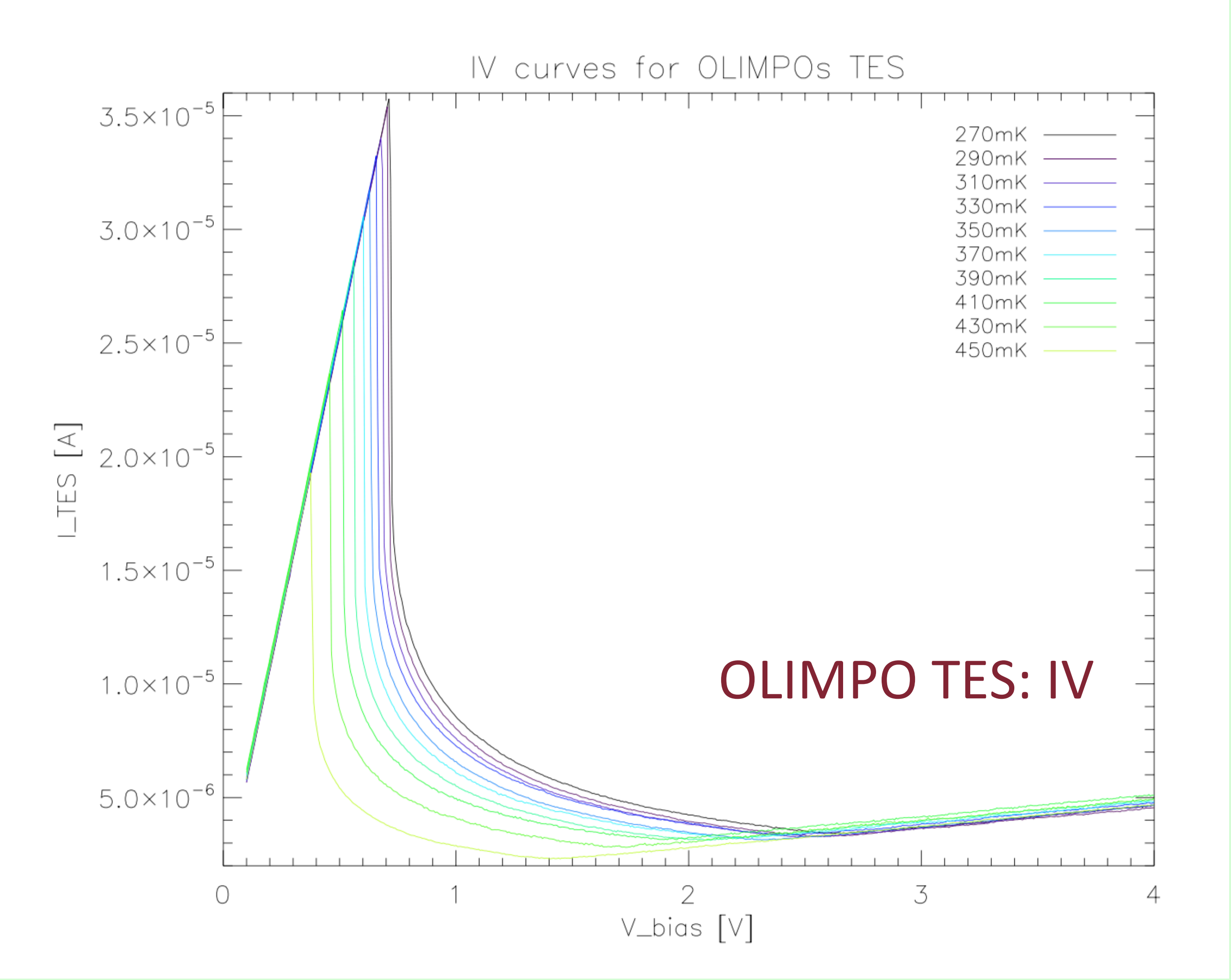
- Test activity in the light of the instrument specificity

- RO electronics design and firmware development

- Calibration
  - Photometric calibration
  - Polarization calibration
  - Spectral calibration
  - Detectors stability

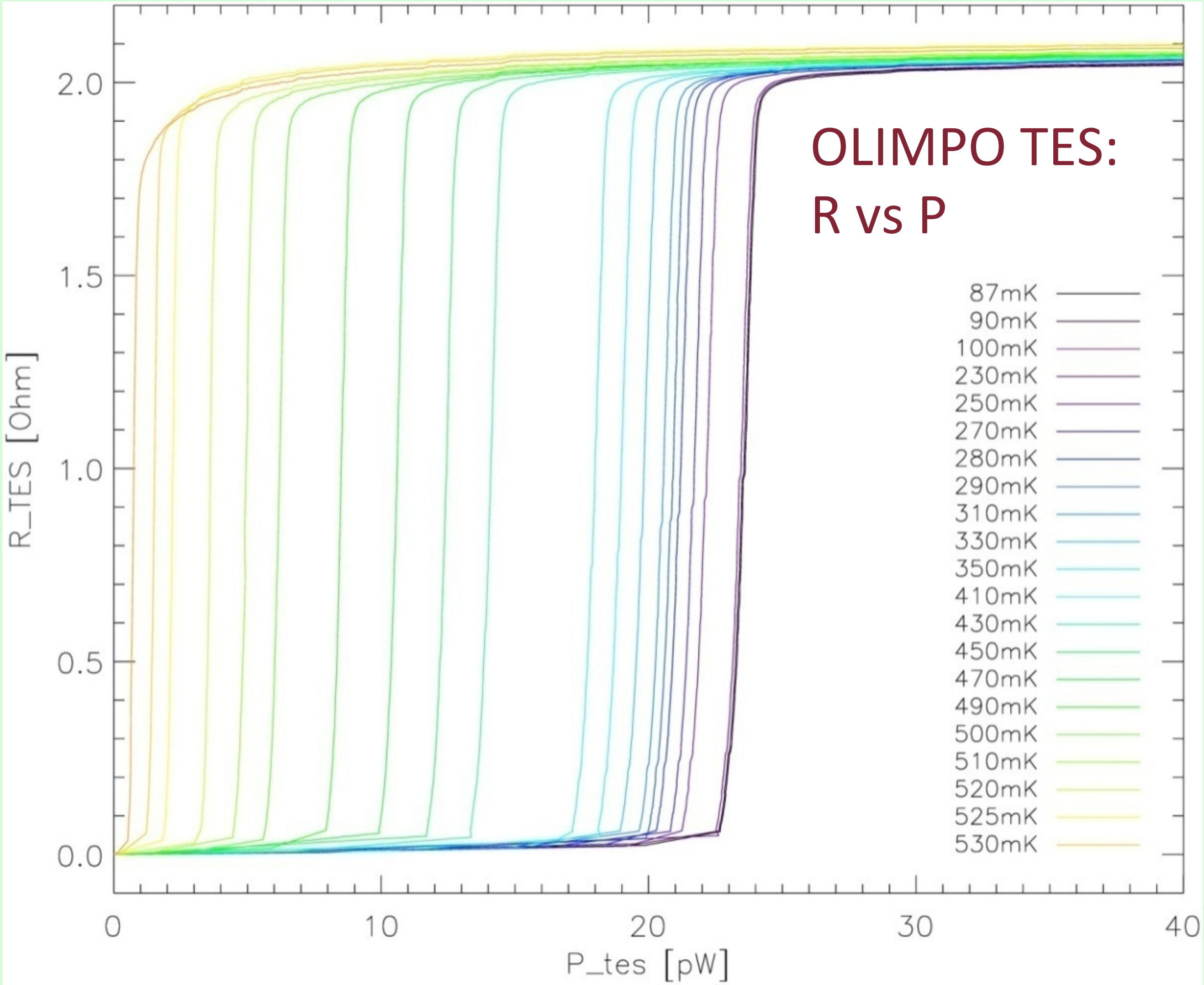
DETECTORS CHARACTERIZATION

- Blind detectors characterization
- TES are characterized measuring the IV curves as a function of the bath temperature



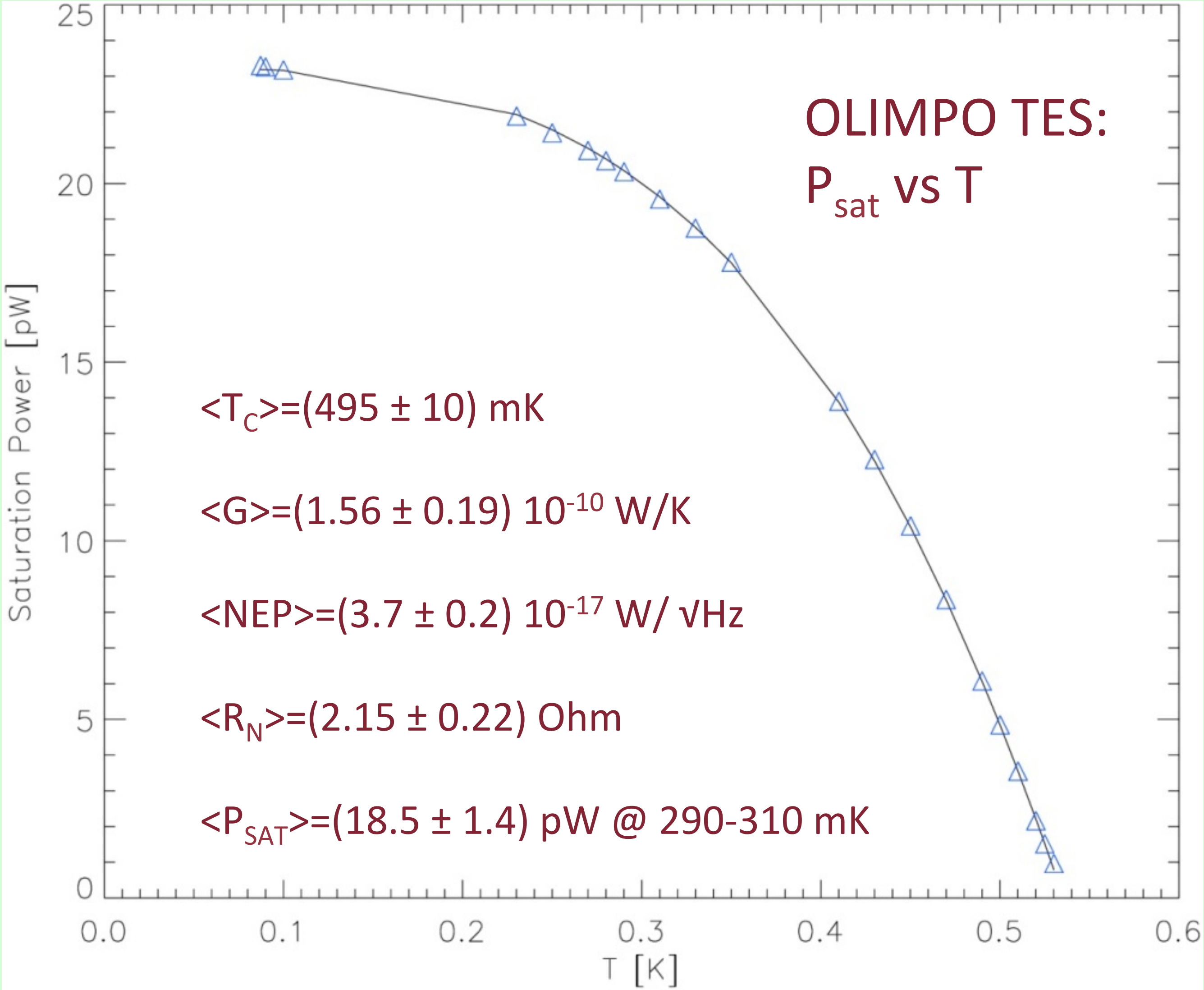
DETECTORS CHARACTERIZATION

- Blind detectors characterization
- TES are characterized measuring the IV curves as a function of the bath temperature
- This allows to determine the Resistance vs TES power curves



DETECTORS CHARACTERIZATION

- Blind detectors characterization
- TES are characterized measuring the IV curves as a function of the bath temperature
- This allows to determine the Resistance vs TES power curves
- $P_{sat}(T)=k\,(T_c^n - T^n)$



DETECTORS DESIGN: LSPE-SWIPE

- The scanning strategy (+ the beam) and the FDM read-out sets the requirements for the TIME CONSTANT. This should include the ETF loop gain:

$$0.1\,\mathrm{ms} < \tau < 15\ \mathrm{ms} \rightarrow \tau = C/[G(1+L)] \rightarrow G > 50\ \mathrm{pW/K}$$

- Photon noise estimations set limits on the THERMAL (phonon) NOISE → G, T_c

$$\begin{cases} NEP_{th}^{140GHz} < 3.6\ 10^{-17}\ W/\sqrt{Hz} \\ NEP_{th}^{220GHz} < 2.4\ 10^{-17}\ W/\sqrt{Hz} \\ NEP_{th}^{240GHz} < 4.3\ 10^{-17}\ W/\sqrt{Hz} \\ NEP_{th}^{270GHz} < 4.5\ 10^{-17}\ W/\sqrt{Hz} \end{cases}$$

$$NEP_{th} \sim \sqrt{4 k_b T_c^2 G F}$$

- Optical load estimation sets limits on the SATURATION POWER:

$$P_{sat} > 2.5\ P_{opt} \rightarrow \begin{cases} P_{sat}^{140GHz} > 23pW \\ P_{sat}^{220GHz} > 10pW \\ P_{sat}^{240GHz} > 33pW \\ P_{sat}^{270GHz} > 35pW \end{cases}$$

$$P_{sat}(T_c) = K(T_c^n - T_{bath}^n)$$

DETECTORS DESIGN: LSPE-SWIPE

From the NEP formula:

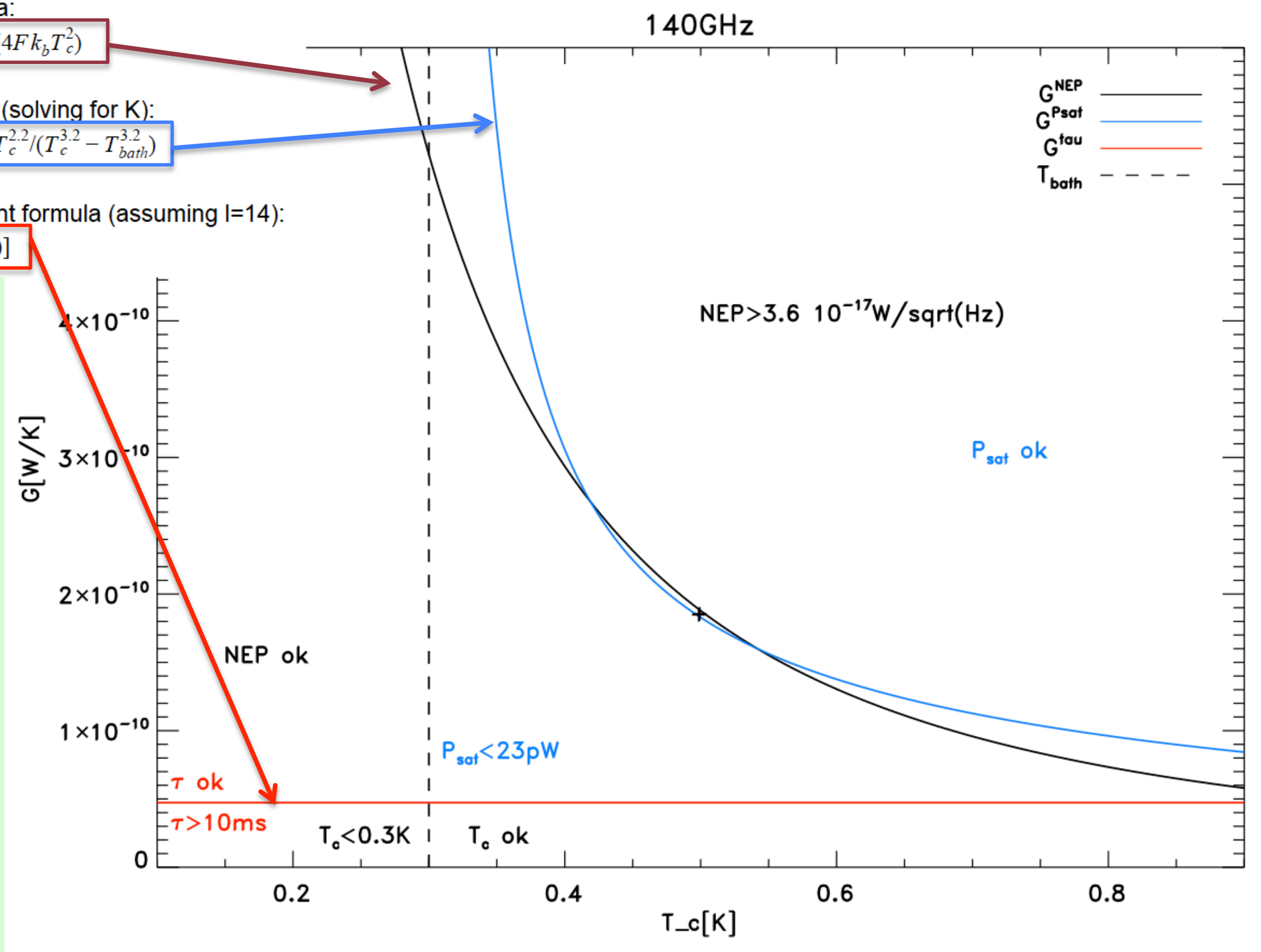
1) $G^{NEP} = NEP^2/(4F k_b T_c^2)$

From the P_{sat} formula (solving for K):

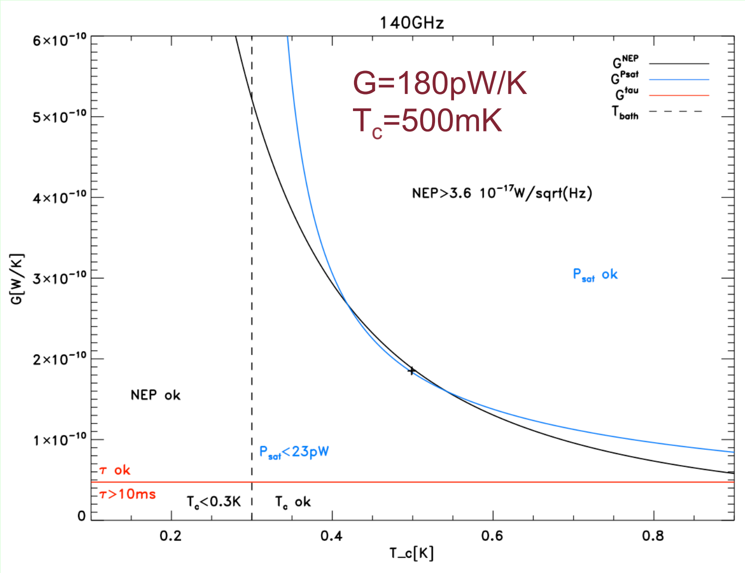
2) $G^{P_{sat}} = 3.2\, P_{sat} T_c^{2.2}/(T_c^{3.2} - T_{bath}^{3.2})$

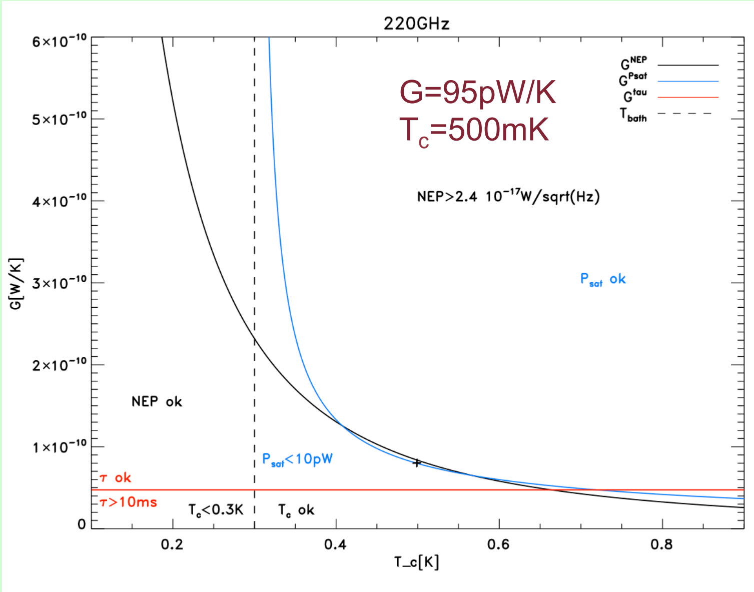
From the time constant formula (assuming l=14):

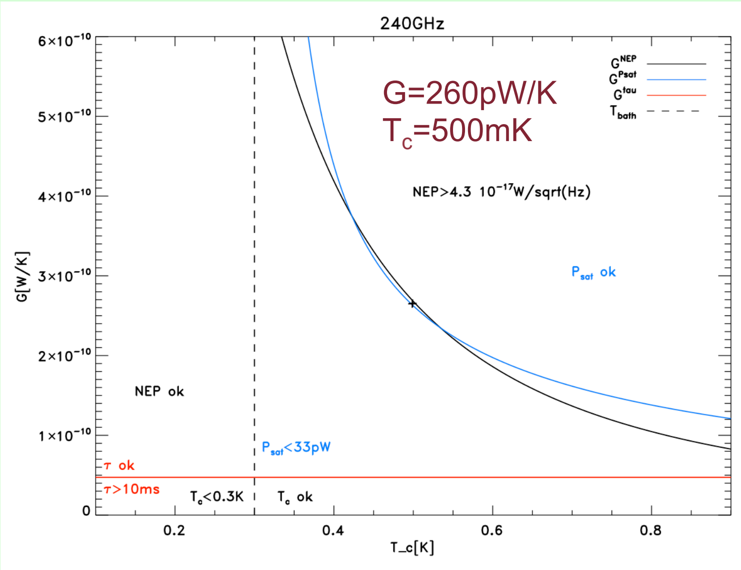
3) $G^{\tau} = C/[\tau(1+l)]$

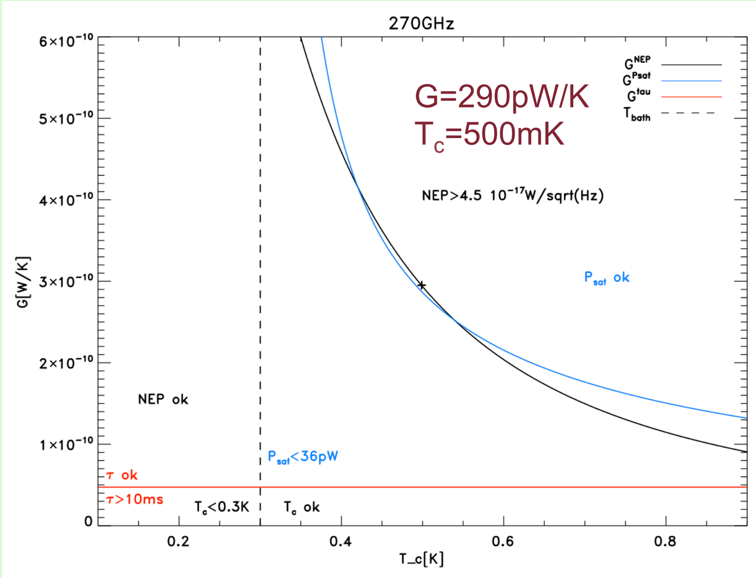


DETECTORS DESIGN: LSPE-SWIPE

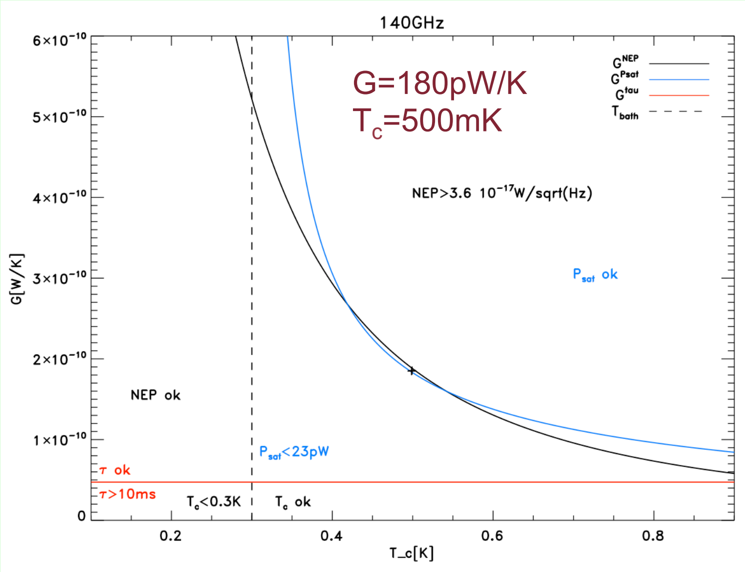


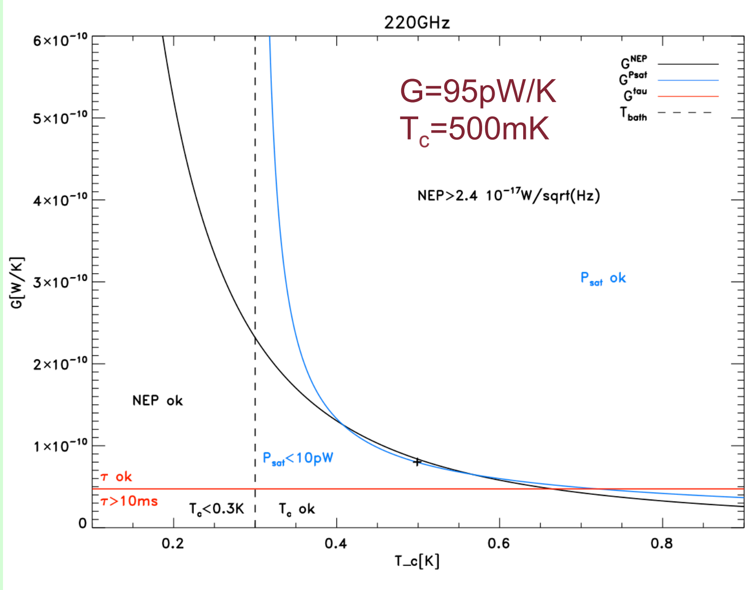


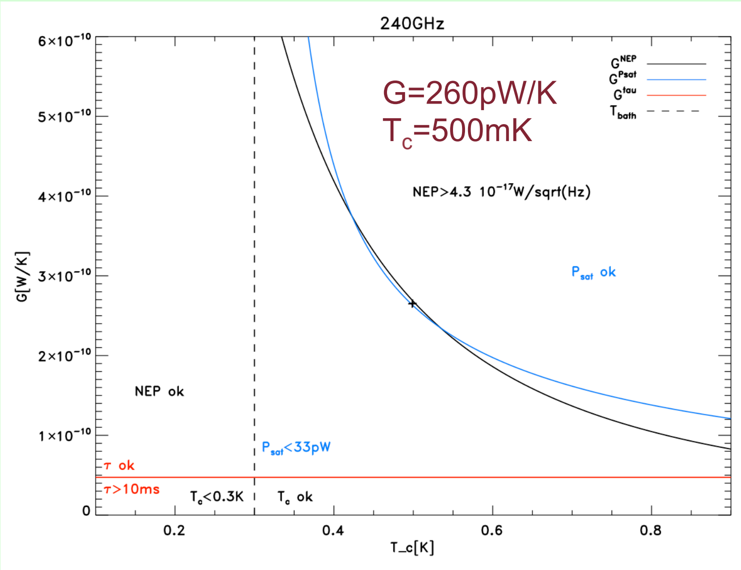




DETECTORS DESIGN: LSPE-SWIPE







- The same combined analysis (Gualtieri et al. JLTP 2016) was applied to the QUBIC TES design (C. Perbost PhD thesis, APC-Paris 7) allowing to spot several issues with saturation power

TEST wrt EXPERIMENT SPECIFICITY

- Detectors characterization is clearly not the only test one needs to do

- Each instrument has its specificity which has to be taken into account:
  - OLIMPO has a DFTS
  - LSPE-SWIPE has multimoded bolometers
  - QUBIC is a bolometric interferometer (with spectral capability)
  - …

- So, either one develops all testing tools from scratch (this is partially mandatory), or we rely on:

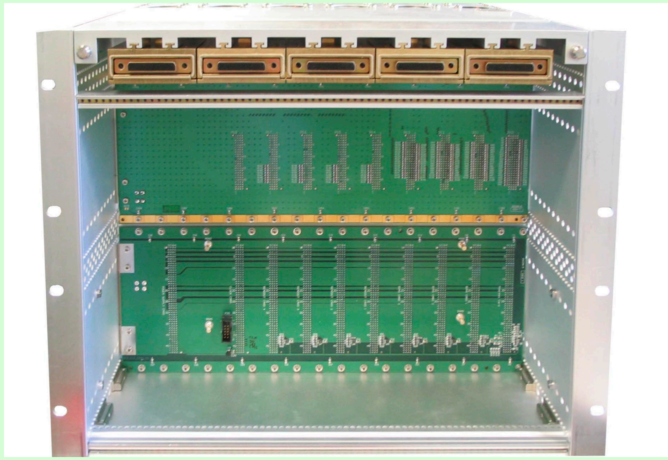
  - Powerful and versatile RO electronics
  - Specific Firmware development
  - User friendly, fully controllable and versatile client hardware and software

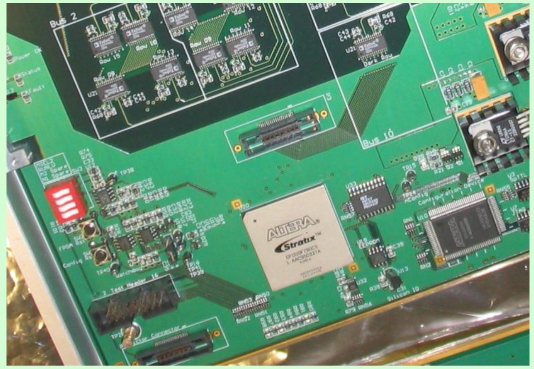
TEST wrt EXPERIMENT SPECIFICITY

- EXAMPLES:
  - UBC's MCE
  - ROACH2
  - QUBIC Studio

TEST wrt EXPERIMENT SPECIFICITY

- EXAMPLES: UBC's MCE





  - Used in:
    - SCUBA2
    - (AdV-)ACT(-Pol)
    - BICEP2,3, Keck Array
    - SPIDER
  - TDM with SQUIDs and TES
  - Complexity of operation and synchronization
  - Necessity to tailor around specific instrument and operations but also to be versatile enough in order to be used on different experiments
  - Dedicated RO electronics with an analog/digital configuration
  - Reprogrammable FPGA based electronics
  - Firmware development
  - Power consumption
  - Cooling system
  - Several tests needed including the SEU

Credits M. Halpern UBC

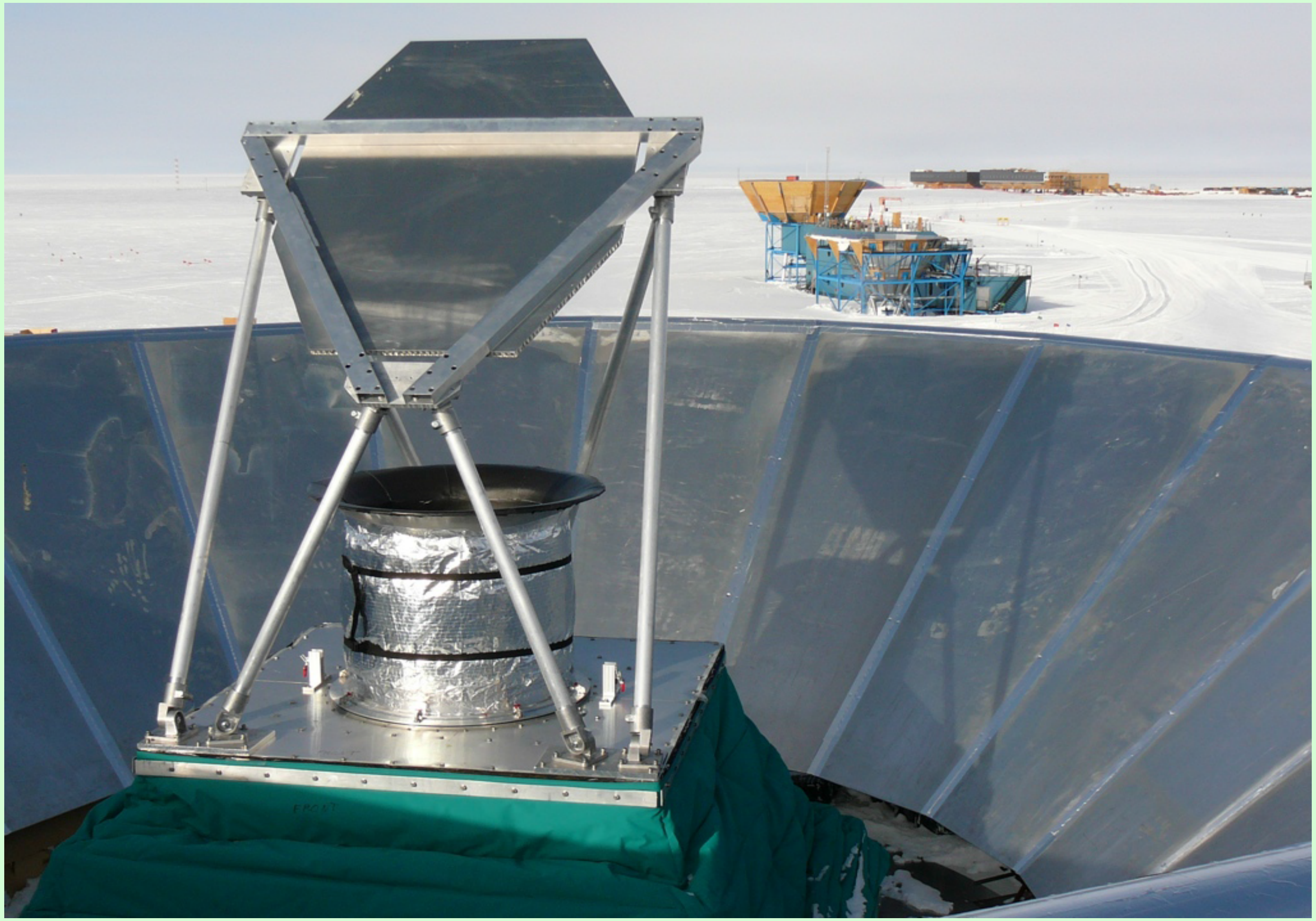
TEST wrt EXPERIMENT SPECIFICITY

- EXAMPLES: UBC’s MCE
  - Tuning the detectors array
  - TES bias depends on the incoming optical power
  - T_c’s varies with the magnetic field
  - All SQUIDs are sensitive to magnetic pick-up
  - In a TDM configuration the SQ2 summing coil is very sensitive to magnetic pick up
  - I_c’s varies with T_{bath}
  - The array is sensitive to the environment so it has to be often re-tuned: need the correct software/hardware tools to set, for instance, the ~2500 parameters to be set for a 1000-pixels array

TEST wrt EXPERIMENT SPECIFICITY

- EXAMPLES: UBC's MCE

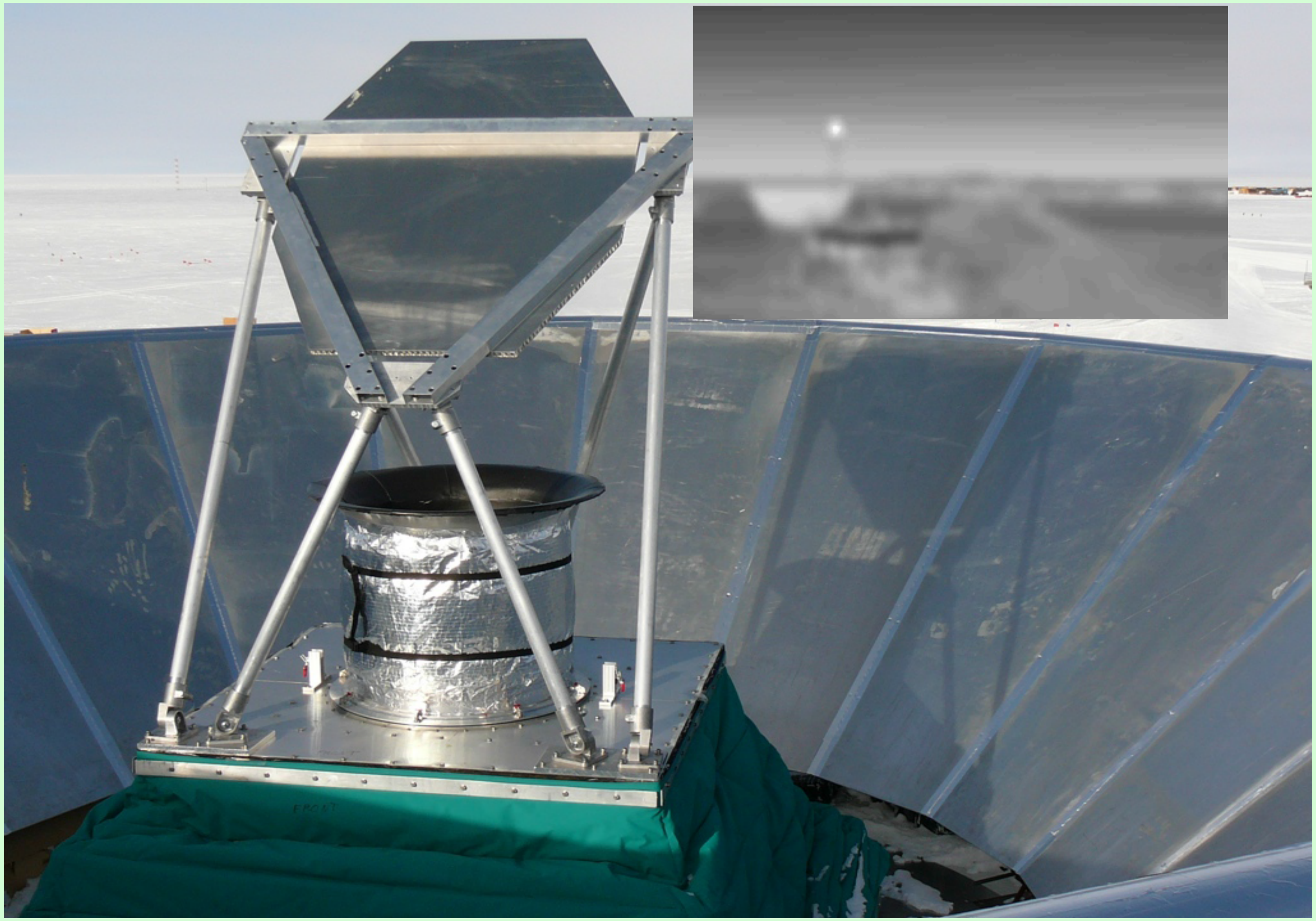
MULTI CHANNEL ELECTRONICS



TEST wrt EXPERIMENT SPECIFICITY

- EXAMPLES: UBC’s MCE

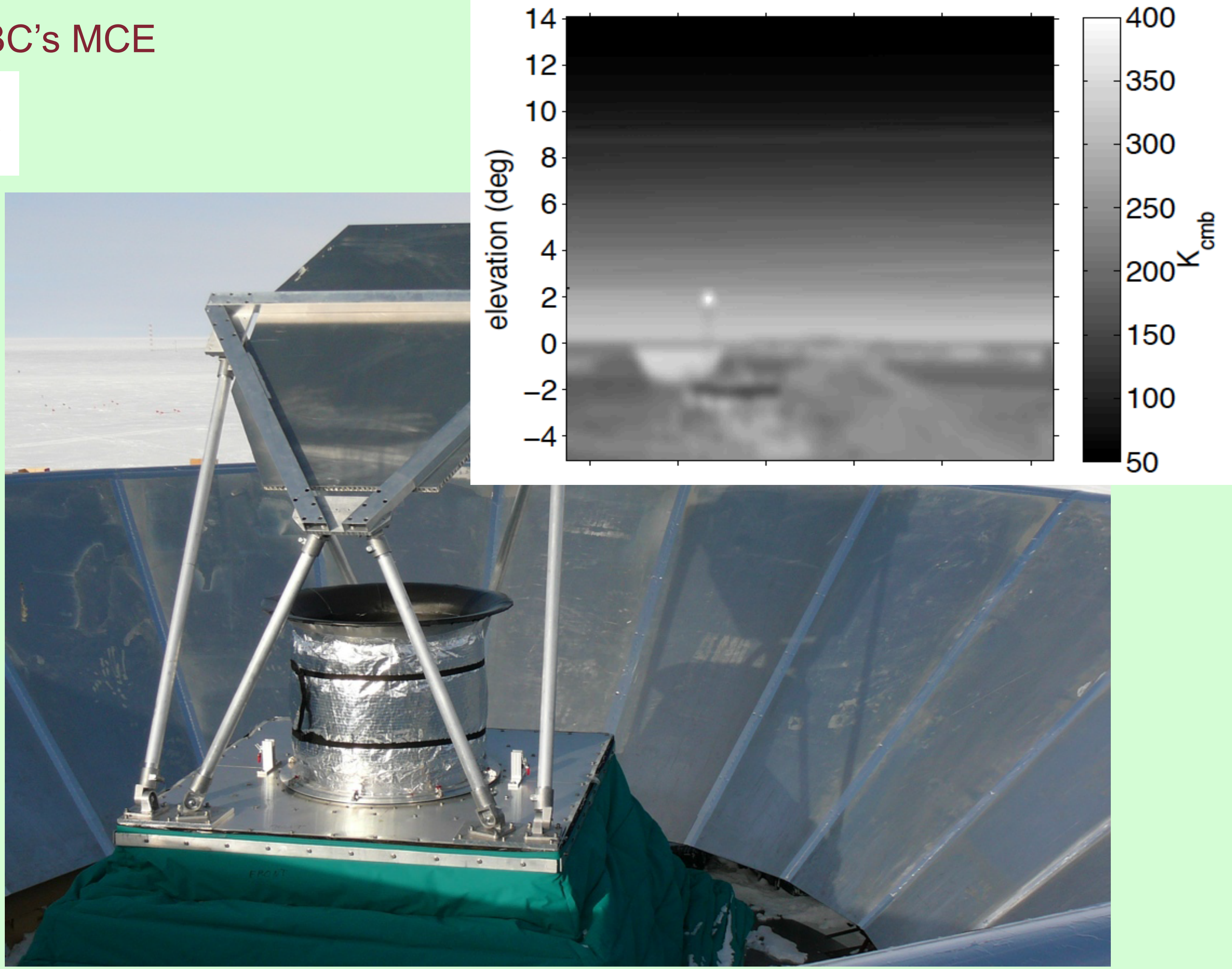
MULTI CHANNEL ELECTRONICS



TEST wrt EXPERIMENT SPECIFICITY

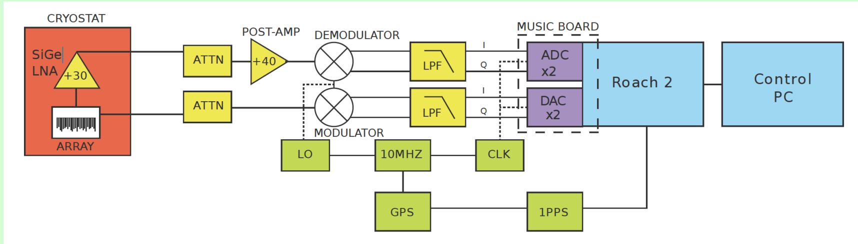
- EXAMPLES: UBC's MCE

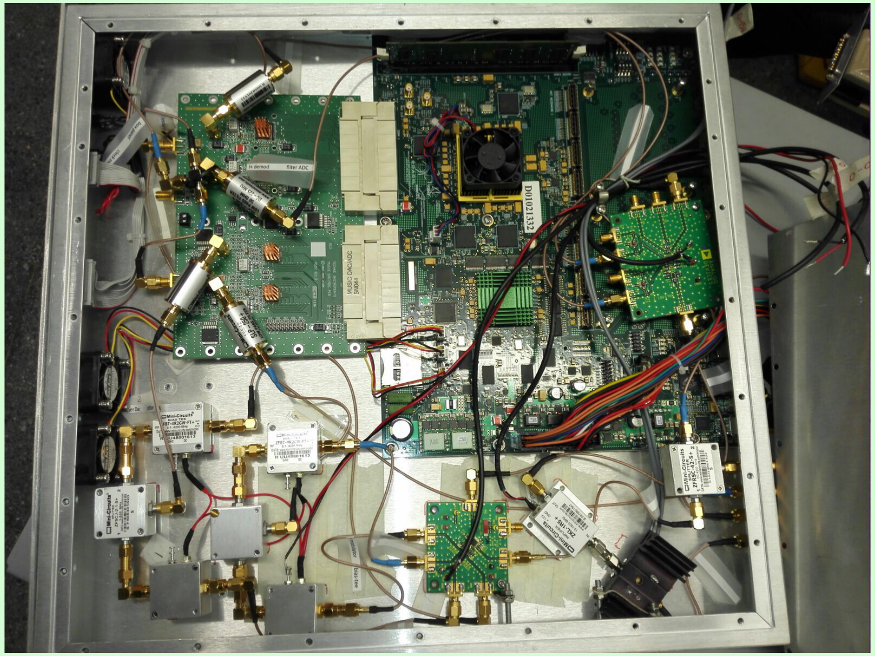
MULTI CHANNEL ELECTRONICS



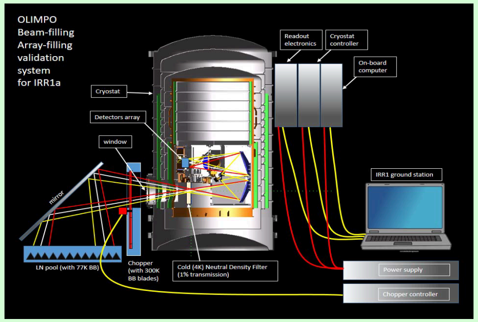
TEST wrt EXPERIMENT SPECIFICITY

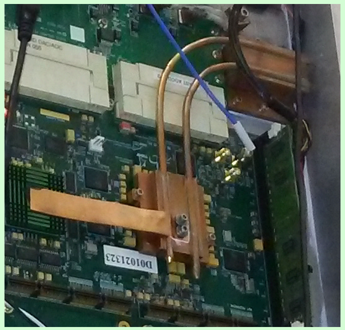
- EXAMPLES: ROACH2
  - OLIMPO electronics is based on the Reconfigurable Open Architecture Computing Hardware (ROACH-2) developed by the Collaboration for Astronomical Signal Processing and Electronics Research (CASPER) based in Berkeley-California
  - MUSIC DAC/ADC: two ADC: 550 msps, 12 bits; two DAC: 1000 msps,16 bit
  - Currently being used to test OLIMPO KIDs tested
  - End to end algorithm for resonance search and detectors preparation





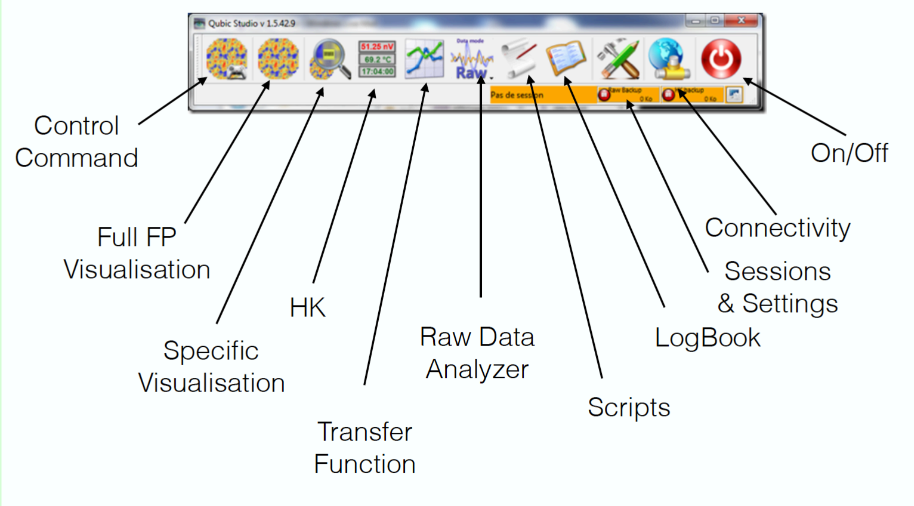
Credits P- Mauskopf, S. Gordon ASU

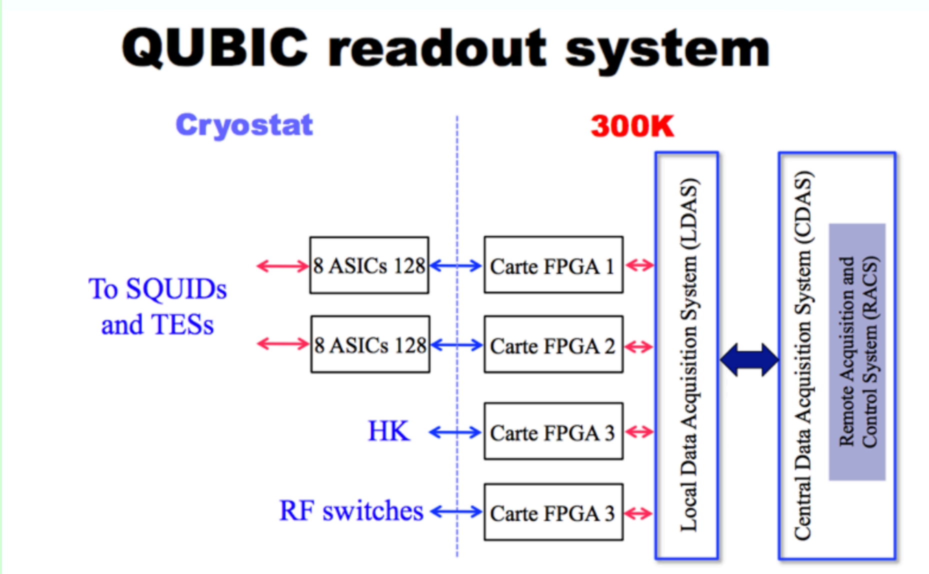




TEST wrt EXPERIMENT SPECIFICITY

- EXAMPLES: QUBIC Studio
  - Control software for QUBIC
  - Used also for PILOT, SUPERCAM, SVOM, SOLAR ORBITER
  - Checks the health of the detectors
  - Controls detectors and housekeeping
  - Scripting capability
  - Customization possible…

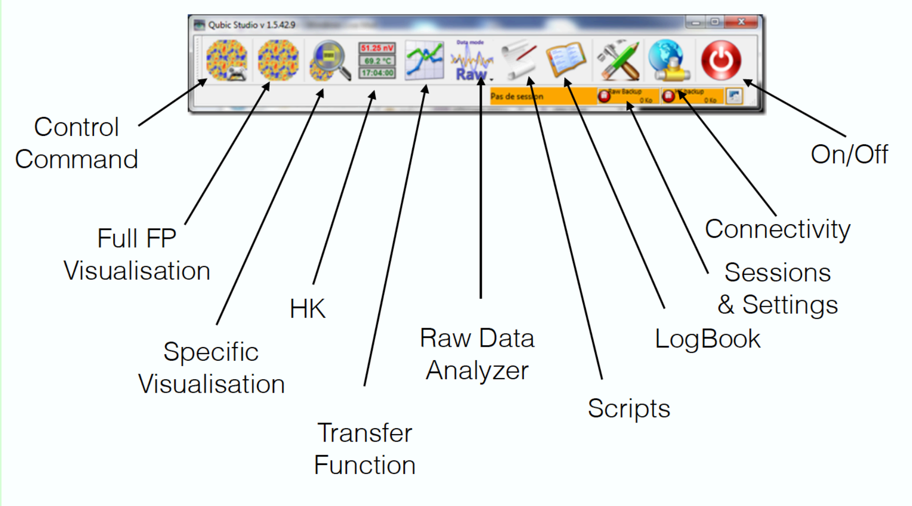


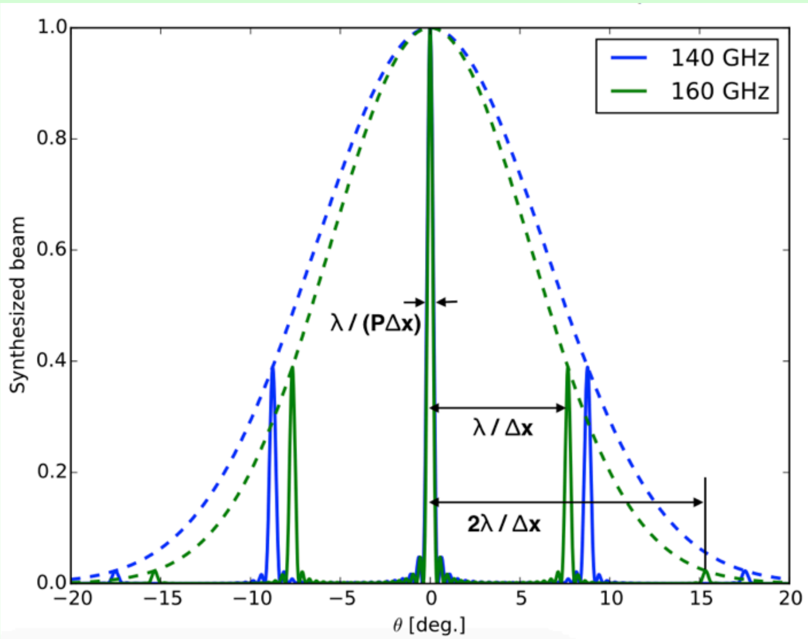


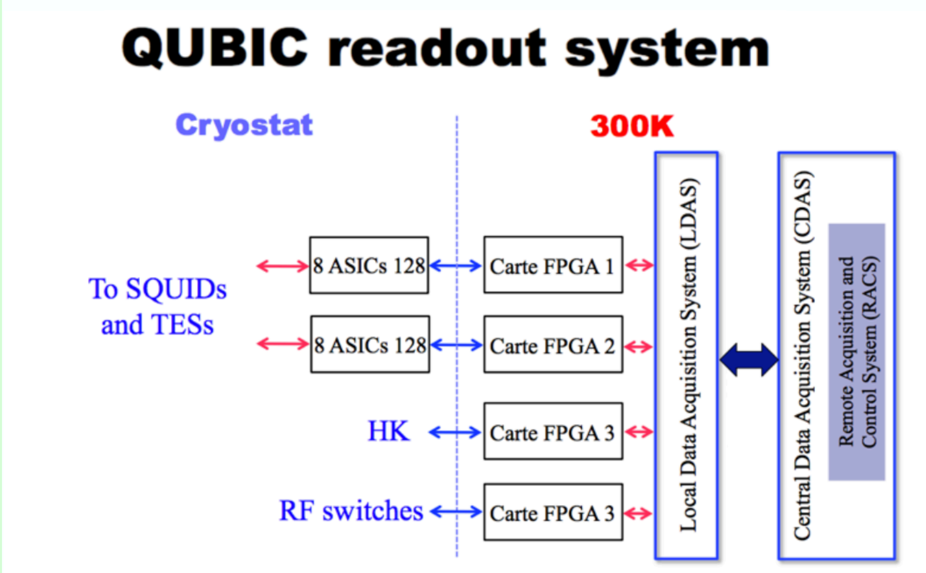
Credits L. Montier,, IRAP Touluse; JC Hamilton APC Paris

TEST wrt EXPERIMENT SPECIFICITY

- EXAMPLES: QUBIC Studio
  - Control software for QUBIC
  - Used also for PILOT, SUPERCAM, SVOM, SOLAR ORBITER
  - Checks the health of the detectors
  - Controls detectors and housekeeping
  - Scripting capability
  - Customization possible…needed in order to fully exploit the Spectro imaging capability of QUBIC







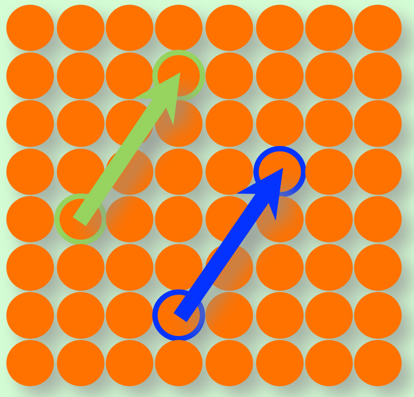
Credits L. Montier,, IRAP Touluse; JC Hamilton APC Paris

CALIBRATION

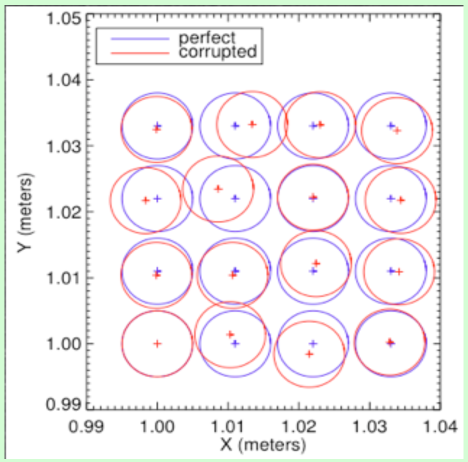
- The raw time-ordered data are pre-processed to clean time-domain systematics an attempt to clean the data of time-domain systematics, remove glitches, cosmic rays, single line filtering, self-contamination (eg cryocooler).
- Data size makes a full inspection and multiple full simulation difficult
- At the pre-processing level we also need to address the noise properties, cross-talk, time constant, bandpasses and, once observing, the overall observation pointing reconstruction, and the individual detector beam profiles
- Detector stability is also fundamental. This can be, for example, achieved with:
  - Cryogenic “cal lamp” (eg. OLIMPO). A criogenic bolometer emitting into our detectors
  - Carbon fiber sources (eg. QUBIC..and Planck).
  - Bias steps (eg. ACT). With the disadvantage not to monitor optical properties
- Photometric and polarization calibration need to be performed both with astronomical sources and with synthetic sources
- For B-modes experiments special attention has to be placed to the polarization calibration, systematic control and polarization angle reconstruction (artificial sources are mandatory…see QUBIC self calibration)

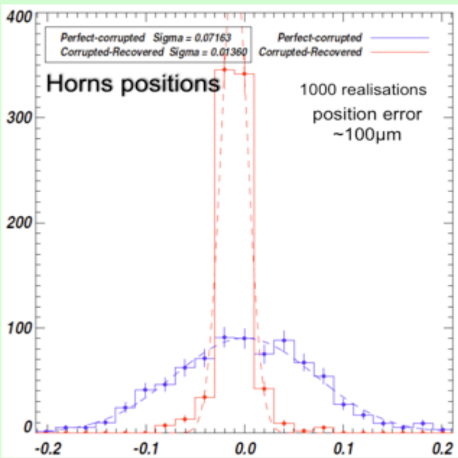
QUBIC SELF-CALIBRATION

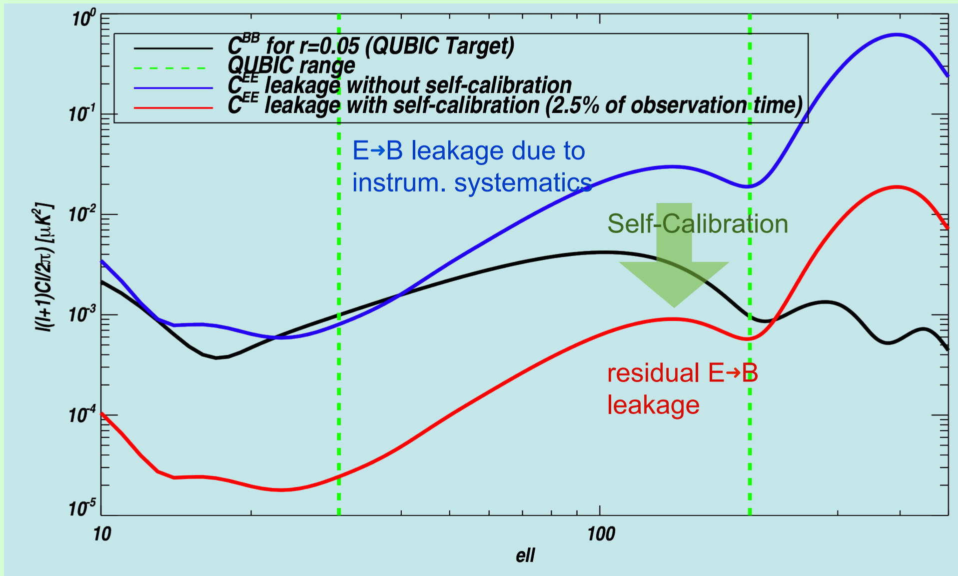
- BI relies on the accurate knowledge of your instrument including the departure from idealities
- A unique possibility to do that, and to handle systematic errors, is the self-calibration
- Use horn array redundancy to calibrate systematics
  - In a perfect instrument redundant baselines should see the same signal
  - Differences due to systematics
  - Allow to fit systematics with an external source on the field



Example: exact horns locations (figure exaggerated !!)





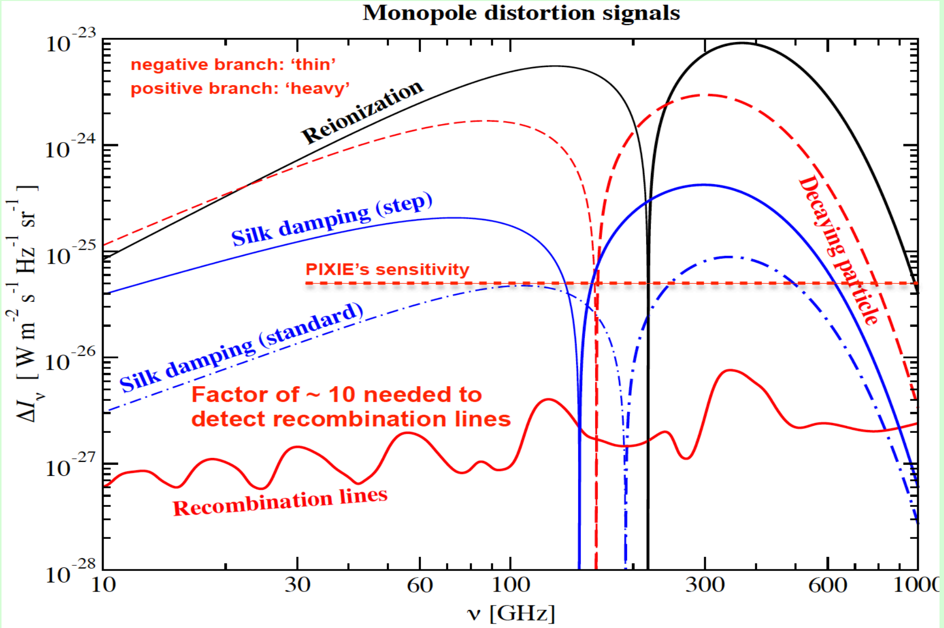


CALIBRATION

- The raw time-ordered data are pre-processed to clean time-domain systematics an attempt to clean the data of time-domain systematics, remove glitches, cosmic rays, single line filtering, self-contamination (eg cryocooler).
- Data size makes a full inspection and multiple full simulation difficult
- At the pre-processing level we also need to address the noise properties, cross-talk, time constant, bandpasses and, once observing, the overall observation pointing reconstruction, and the individual detector beam profiles
- Detector stability is also fundamental. This can be, for example, achieved with:
  - Cryogenic “cal lamp” (eg. OLIMPO). A criogenic bolometer emitting into our detectors
  - Carbon fiber sources (eg. QUBIC..and Planck).
  - Bias steps (eg. ACT). With the disadvantage not to monitor optical properties
- Photometric and polarization calibration need to be performed both with astronomical sources and with synthetic sources
- For B-modes experiments special attention has to be placed to the polarization calibration, systematic control and polarization angle reconstruction (artificial sources are mandatory…see QUBIC self calibration)
- Spectral calibration….

SPECTRAL CALIBRATION

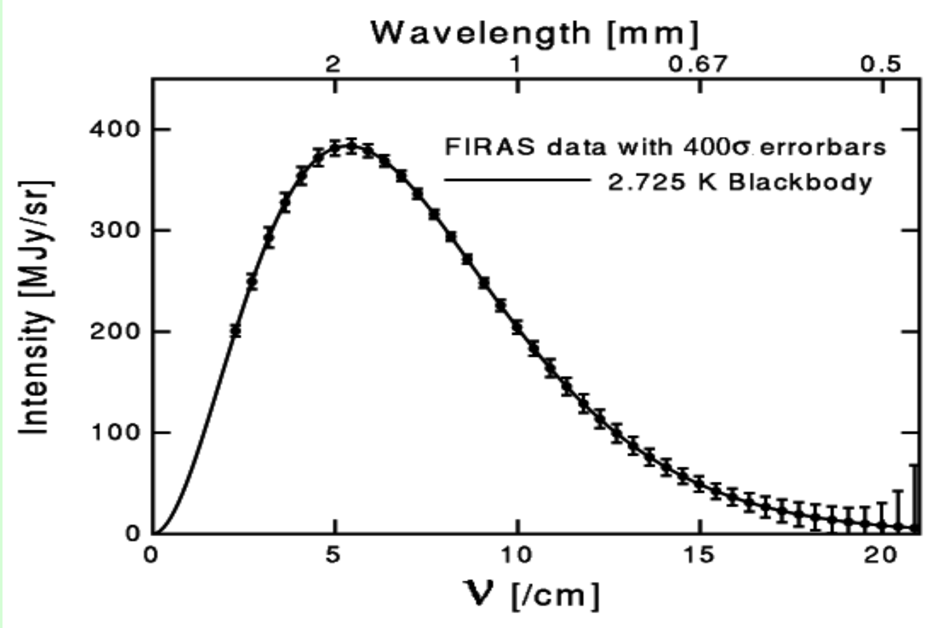
- CMB spectral distortion is an exciting science
- Most of the signals are on the monopole, extremely faint and smooth in frequency
- This requires excellent sensitivity (both detectors and photon noise wise) and absolute calibration

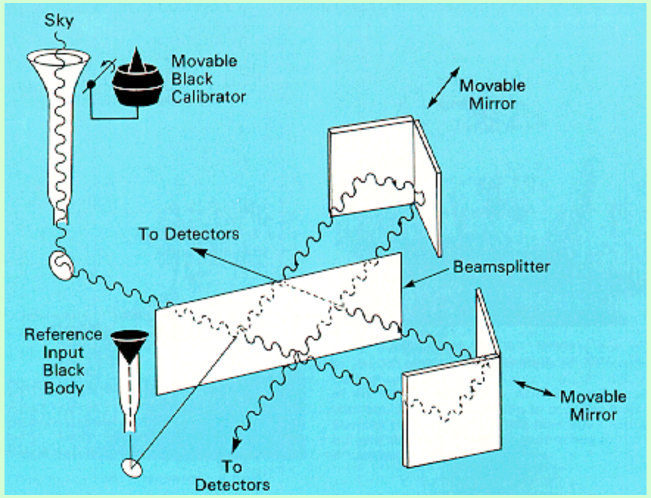


Credits J. Chluba, U. Manchester

SPECTRAL CALIBRATION

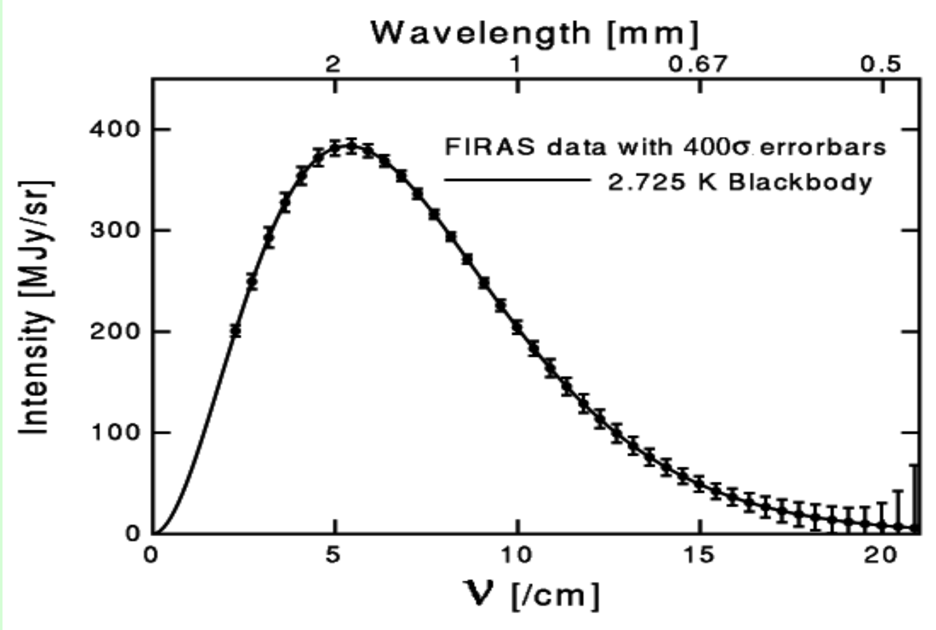
- CMB spectral distortion is an exciting science
- Most of the signals are on the monopole, extremely faint and smooth in frequency
- This requires excellent sensitivity (both detectors and photon noise wise) and absolute calibration
- Today, the best results on Spectral Distortion limits are 20 year old (FIRAS) and if you think about what has happened in the last 20 years in CMB anisotropies this is surprising



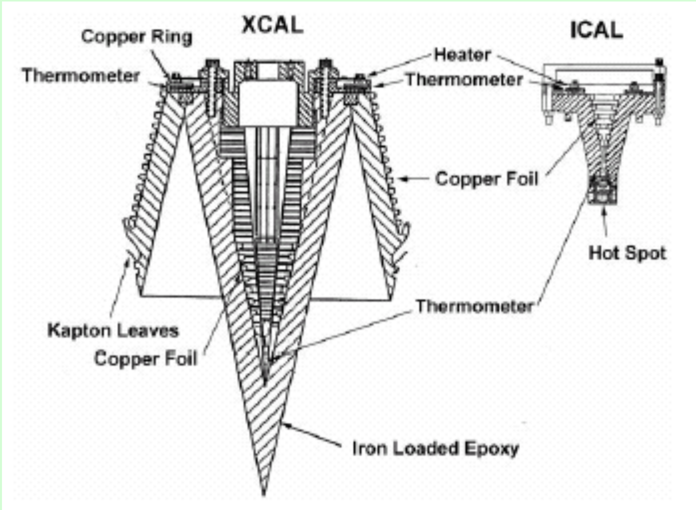


SPECTRAL CALIBRATION

- CMB spectral distortion is an exciting science
- Most of the signals are on the monopole, extremely faint and smooth in frequency
- This requires excellent sensitivity (both detectors and photon noise wise) and absolute calibration
- Today, the best results on Spectral Distortion limits are 20 year old (FIRAS) and if you think about what has happened in the last 20 years in CMB anisotropies this is surprising

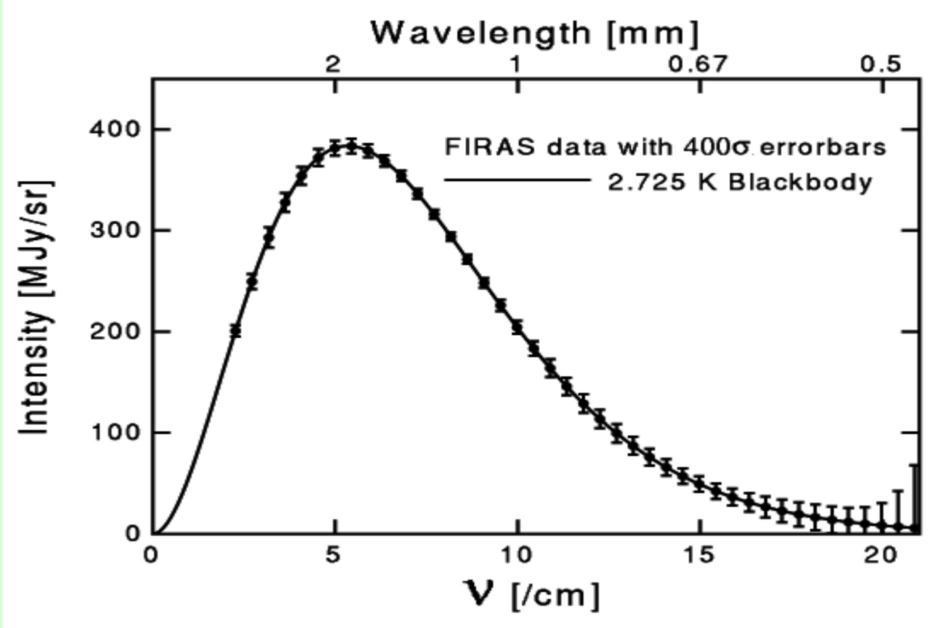


- Even more surprising is that COBE-FIRAS sensitivity limit is dictated by the amount of time they observed the X-cal and possibly by its emissivity and low frequencies



SPECTRAL CALIBRATION

- CMB spectral distortion is an exciting science
- Most of the signals are on the monopole, extremely faint and smooth in frequency
- This requires excellent sensitivity (both detectors and photon noise wise) and absolute calibration
- Today, the best results on Spectral Distortion limits are 20 year old (FIRAS) and if you think about what has happened in the last 20 years in CMB anisotropies this is surprising



- Even more surprising is that COBE-FIRAS sensitivity limit is dictated by the amount of time they observed the X-cal and possibly by its emissivity and low frequencies
- It seems time to start to invest on studying absolute calibrators for CMB distortion. An example is what PIXIE is doing