HYMAS-X: Superconducting On-Chip Filterbank Spectrometers for Hyperspectral Atmospheric Microwave Sounding

C.N. Thomas[1*], S. Withington[1], D. J. Goldie[1], P. Hargrave[2], R.V. Sudiwala[2] and P.K. Dongre[2]

[1]Cavendish Laboratory, University of Cambridge

[2]School of Physics and Astronomy, Cardiff University

***cnt22@cam.ac.uk**

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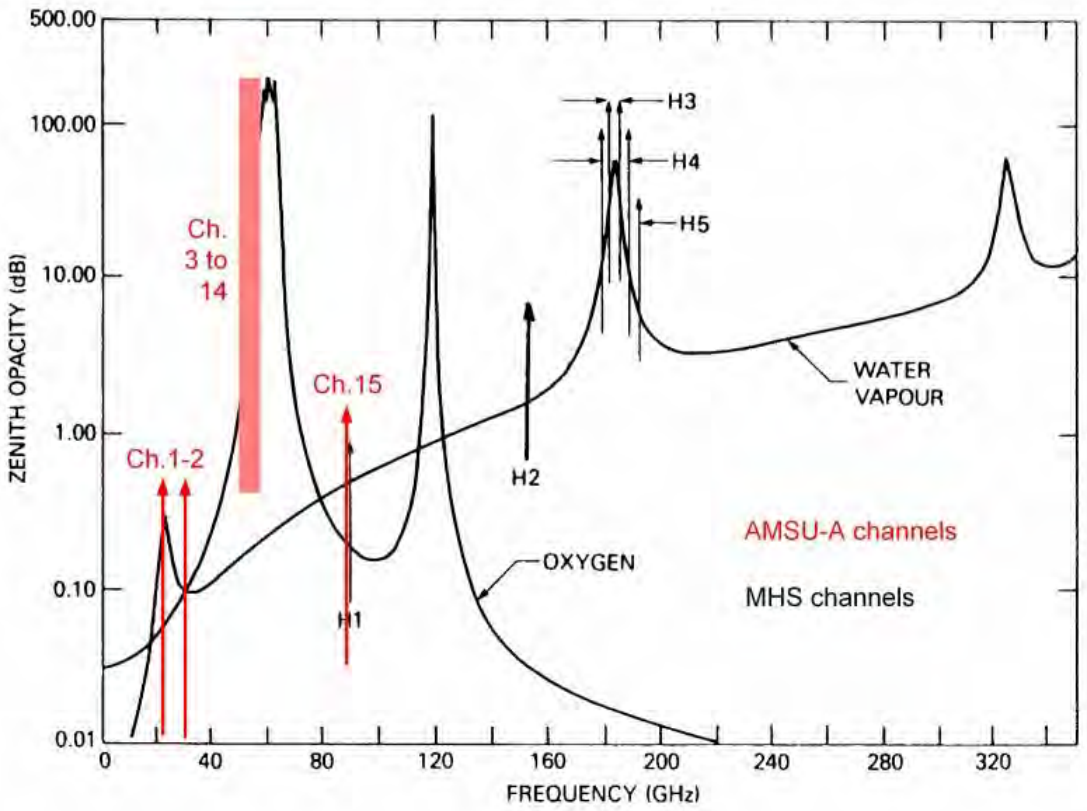
Microwave (MW) atmospheric sounding

- Instruments measure total power in narrow spectral channels in range 20-250GHz. Recover vertical profiles from spectral information.



- O_2 line complex at 60GHz used for temperature sounding.
- H_2O line at 183GHz used for humidity sounding.

AMSU-A and MHS channels as taken from www.eumetsat.int

‘Hyperspectral’ capability

- Current MW sounder channel counts (~20) & sensitivity low compared with IR counterparts…
- … but have critical **‘all-weather’** capability.
- Improved ‘hyperspectral’ MW sounder concept:
  - Deliver **large number of channels** (~100) at **higher resolution** (R>500)
  - **Improve radiometric sensitivity**.
- Significant impact on numerical weather prediction.
- **How can we achieve this?**

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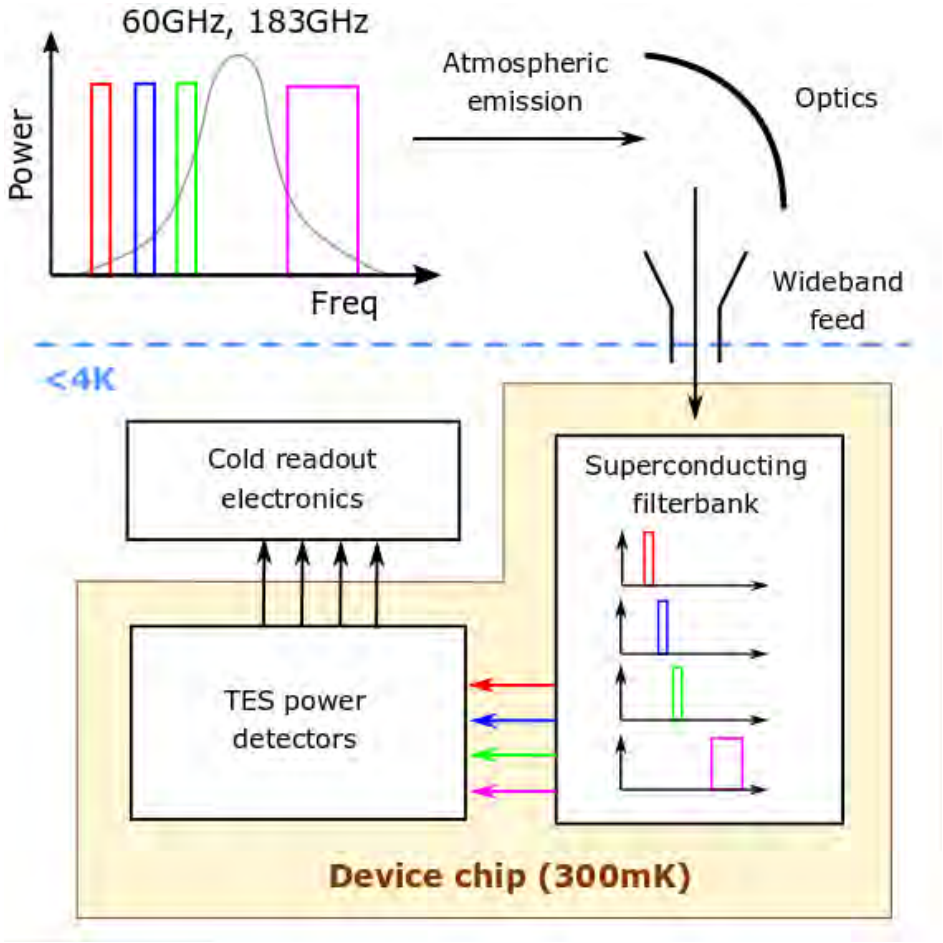
Superconducting on-chip filterbank spectrometers

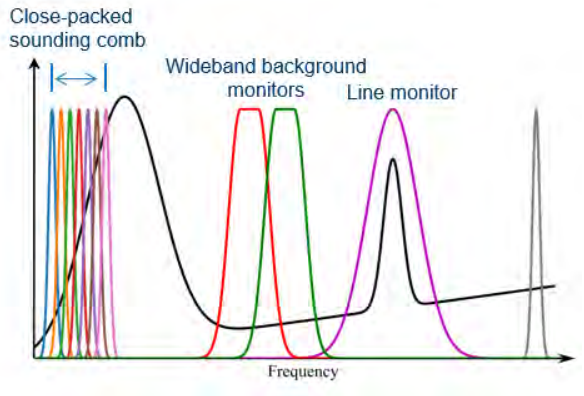


- Channels defined at signal frequency prior to detection. No down-conversion!
- Filters and detectors fabricated together on same chip – **'on-chip'**
- Implemented using superconducting electronics.
- Chips produced by micro-fabrication. Easy to reproduce.
- Superconducting MMIC!

Advantages for hyperspectral sounding

- **Compact. High channel counts per chip**
  - Negligible ohmic losses allow filter miniaturisation without performance loss.
- **TES detectors give high sensitivity**
  - TES at 0.3K can achieve **NEP < 10^{-16} W/Hz$^{0.5}$**
  - Linear/high dynamic range/self-calibration.
  - Workhorse detector for high-sensitivity science
- **Operation up to THz frequencies**
  - Instantaneous observing bandwidth limited only by feed.
- **Flexible channel shape & placement**

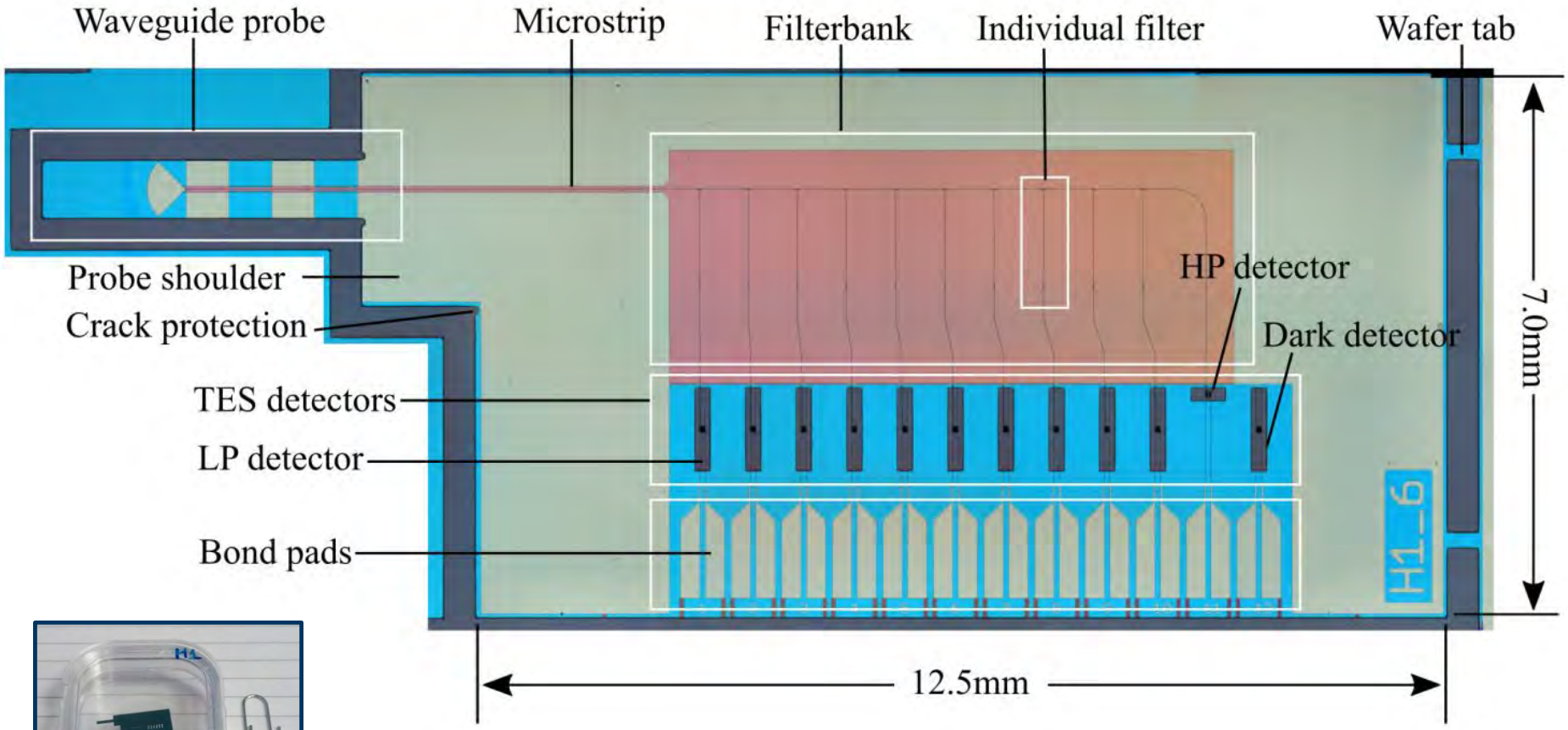
10 channel prototype for 60GHz
(No compactification – more possible!)



HYMAS and HYMAS-X

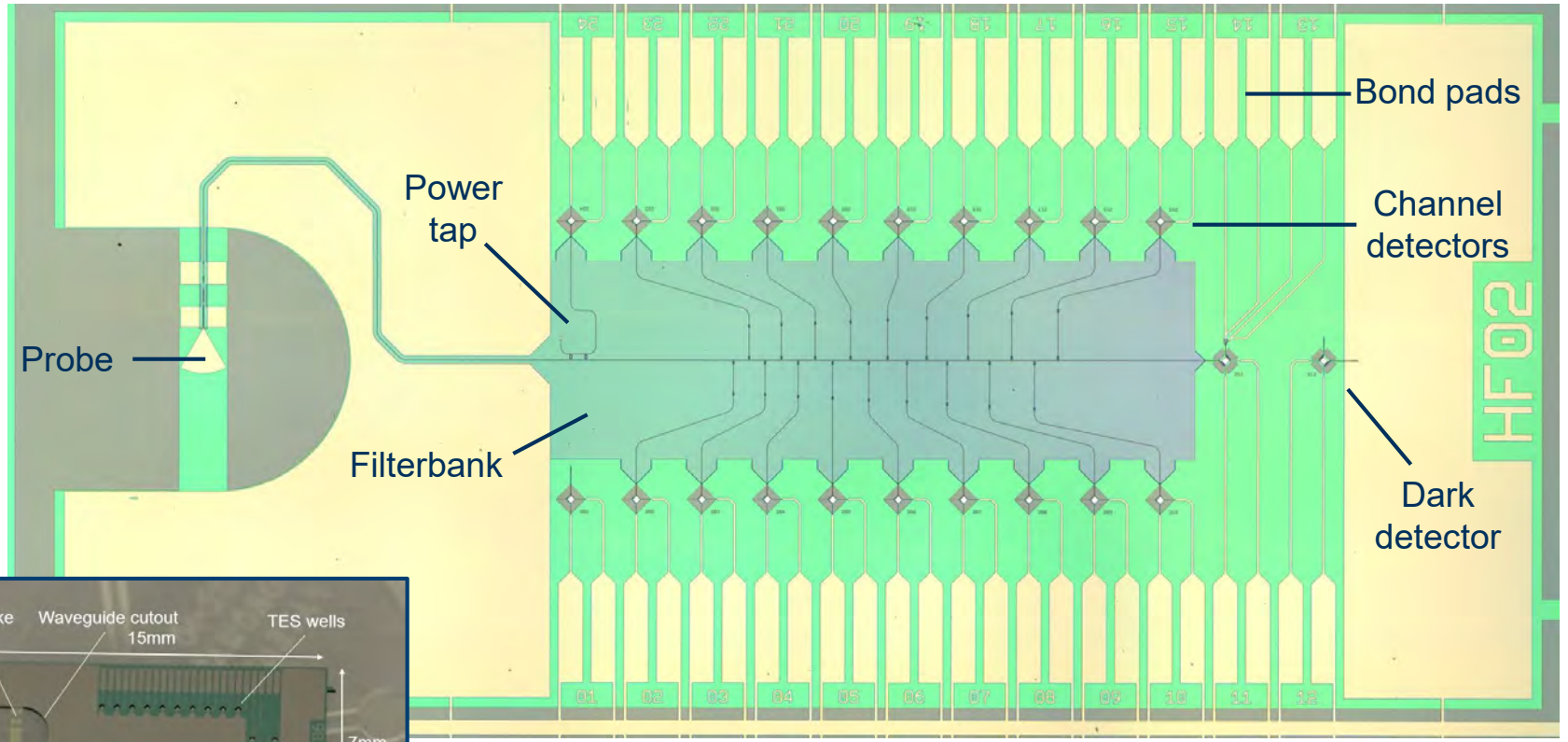
- CEOI funded studies to develop superconducting on-chip spectrometer technology for atmospheric sounding.
- **HYMAS (complete)**
  - 1st generation low-frequency (LF) chips for temperature sounding (60GHz)
- **HYMAS-X (underway)** *('X' is for extended)*
  - 2nd generation enhanced LF chips. (eLF)
  - 1st generation high-frequency (HF) chips for humidity sounding (183GHz)
  - Instrument concept study.
  - **Device fabrication nearly complete and first devices in testing…**
  - All devices fabricated in Cambridge, precision waveguide blocks in Cardiff.

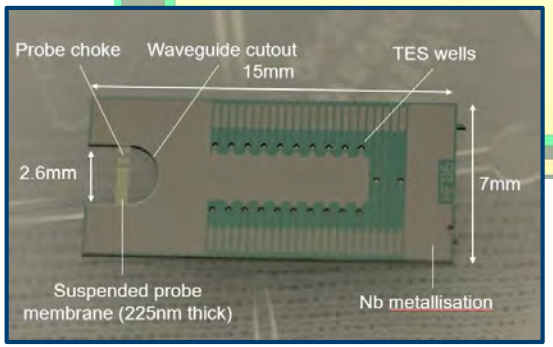
LF chips for 60 GHz (HYMAS/HYMAS-X)



1st generation (LF) tested. 2nd generation (eLF) fabricated.

HF chips for 180GHz (HYMAS-X)



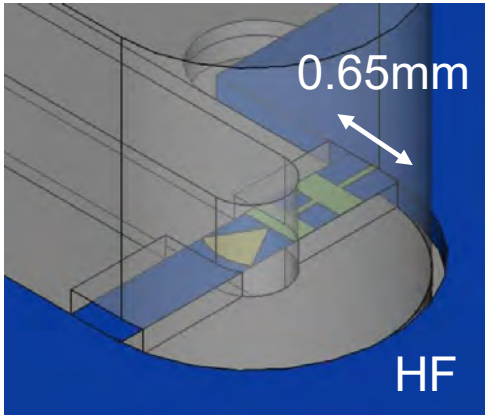


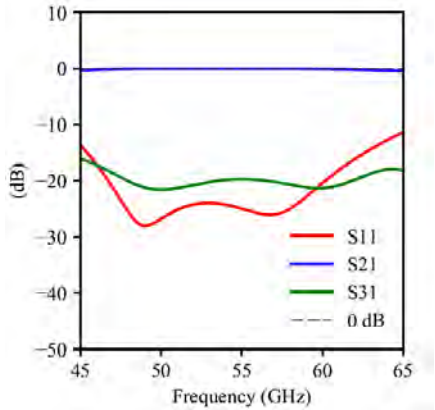
Etch test device

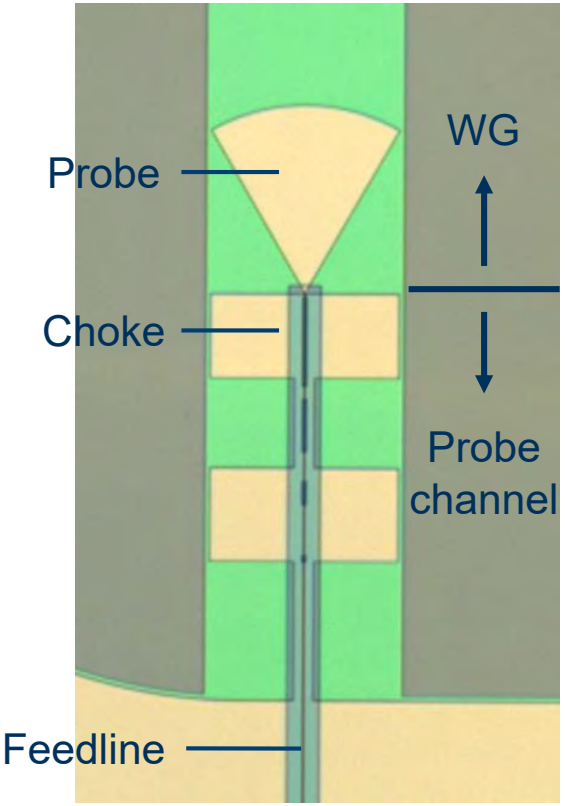
In fabrication – testing soon!

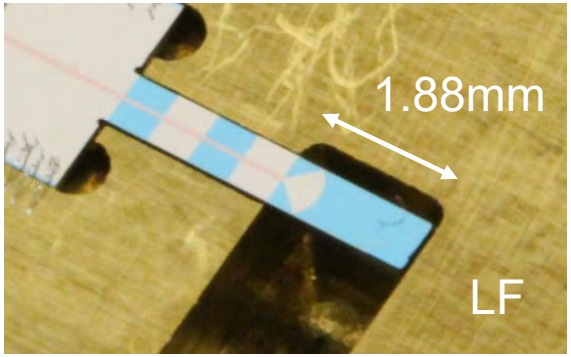
Radial probe transition from waveguide

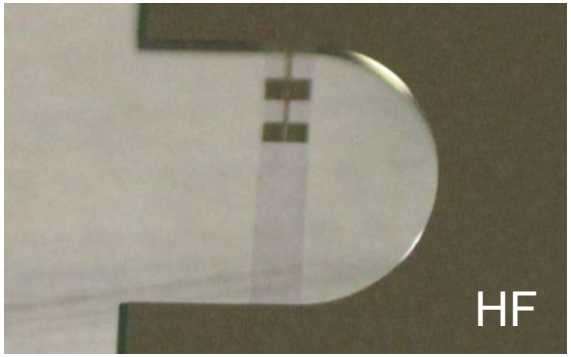
- Wideband designs for **45-65GHz (LF)** and **140-220 GHz (HF)** developed.



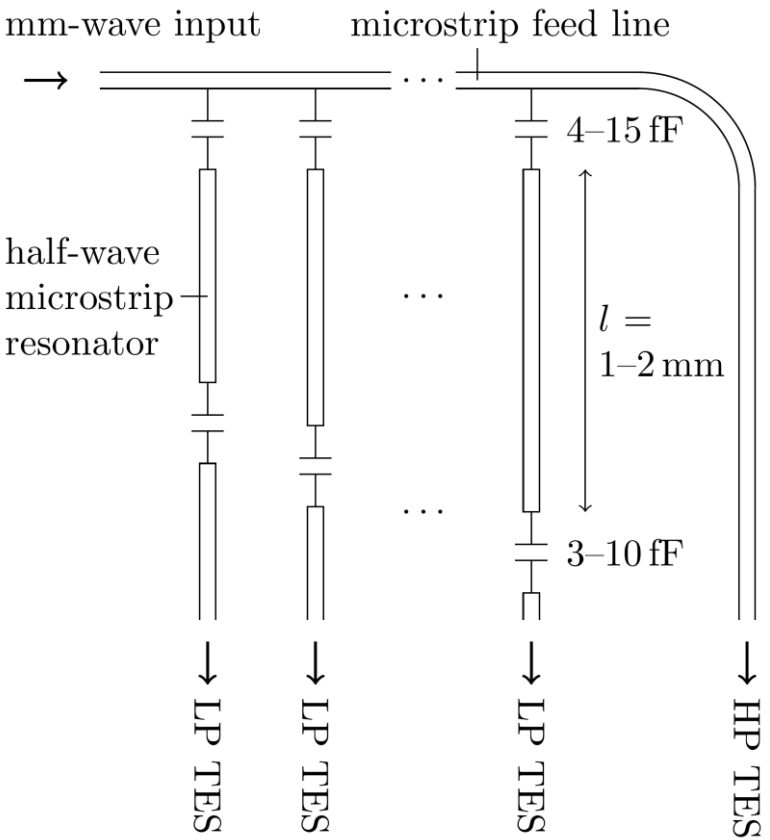




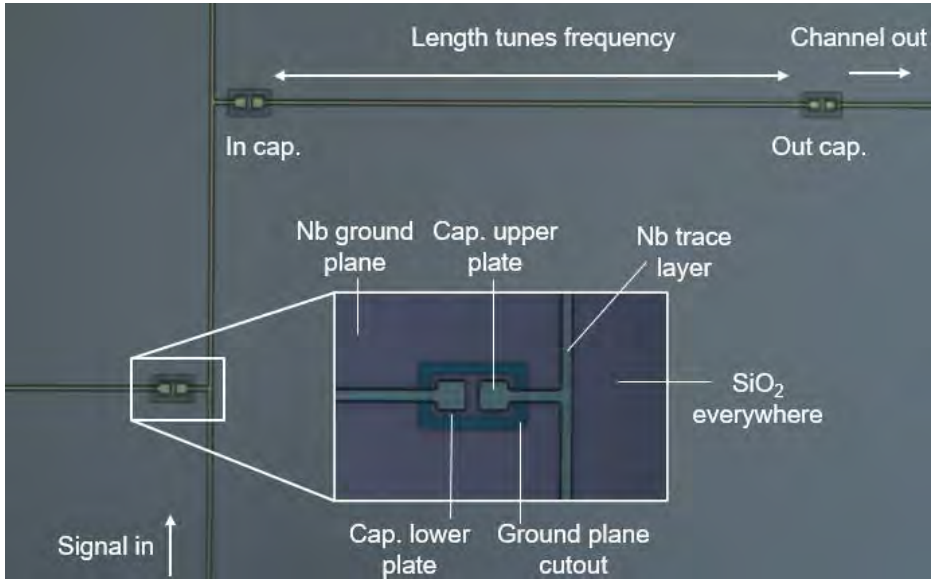




Filterbank design

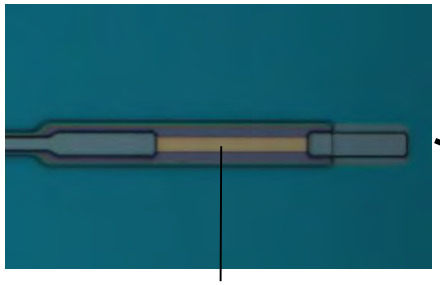


- Half-wave resonator design.
- Resonator length tunes centre frequency.
- Coupling capacitors tune R up to limit set by internal losses.
- Efficiency of basic designed limited to 50%.

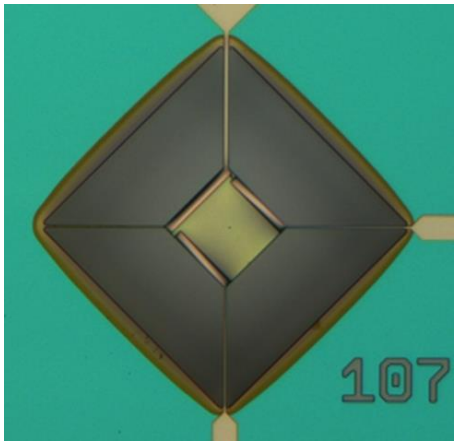


Transition edge sensors (TES) detectors

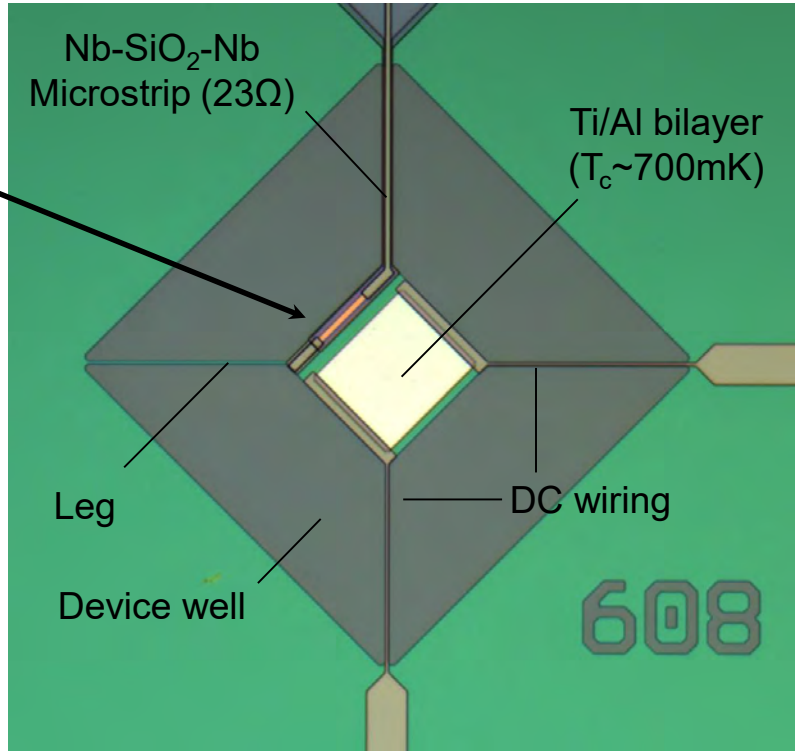
23Ω termination resistor



AuCu resistor strip



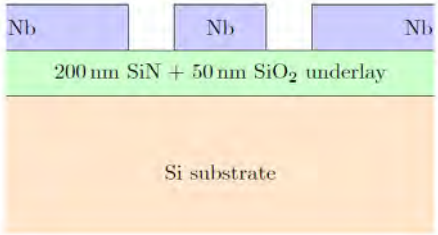
Released island
(no bilayer)



Unreleased TES from HF chip

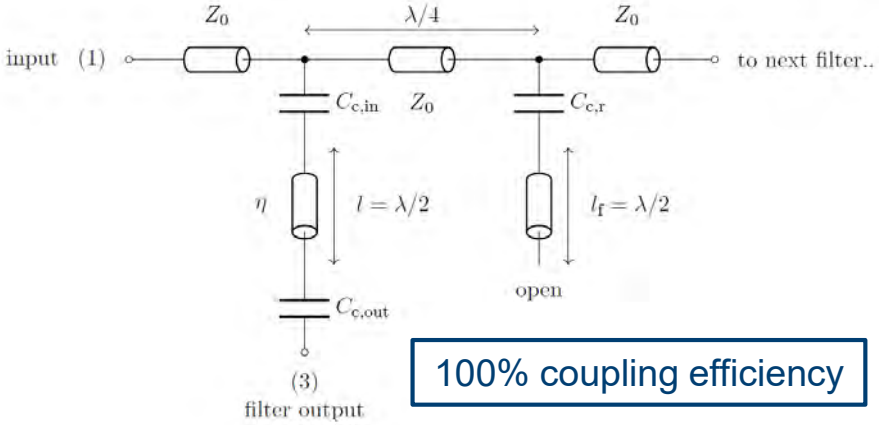
New designs on HYMAS-X eLF and HF chips

CPW filters for higher R



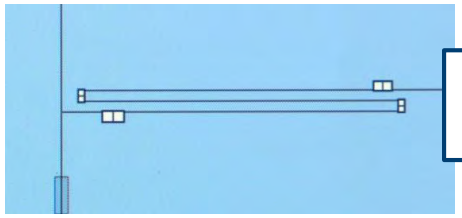
Eliminate lossy dielectrics for high R

Fully-coupled filters



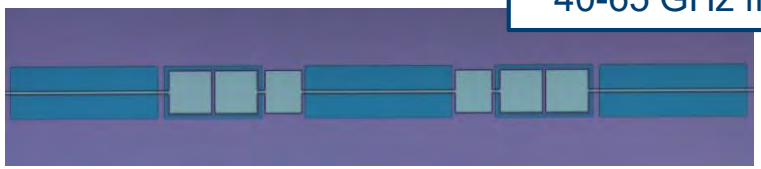
100% coupling efficiency

'Wide' bandwidth filters

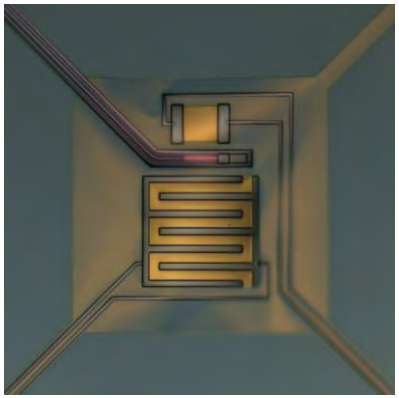


5GHz wide channel filter

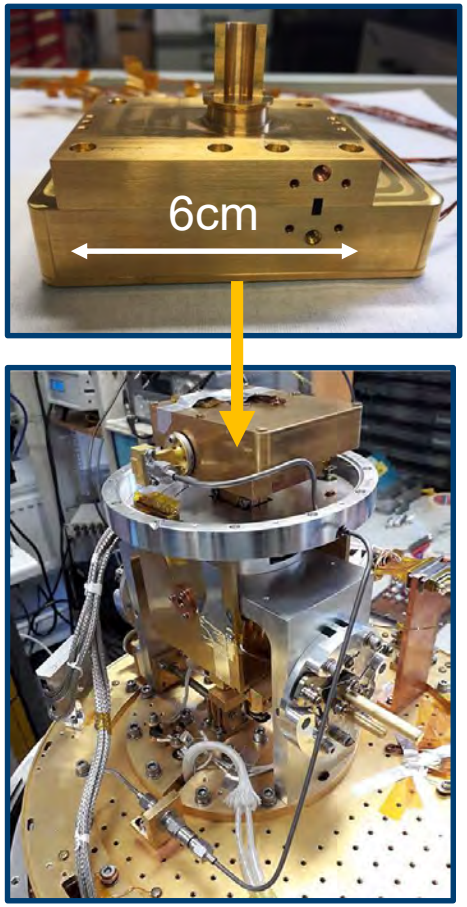
40-65 GHz filter

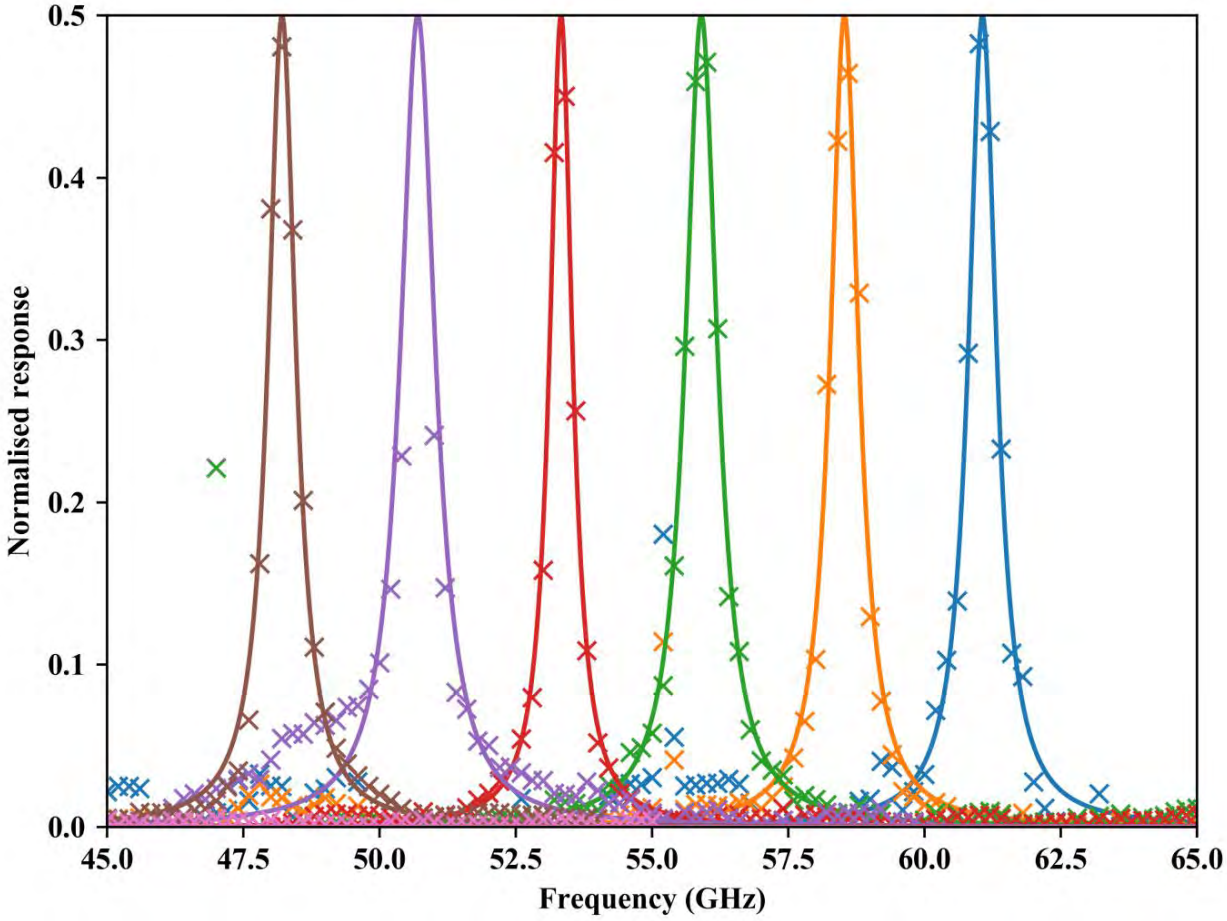


On-chip blackbody loads



Measured performance: 1st generation LF chips





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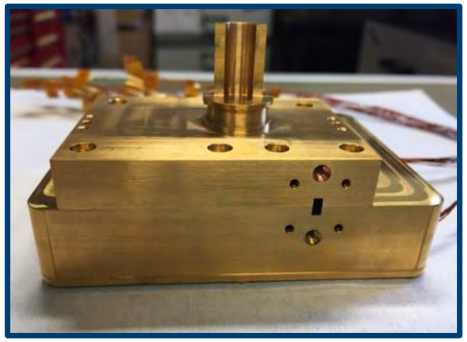
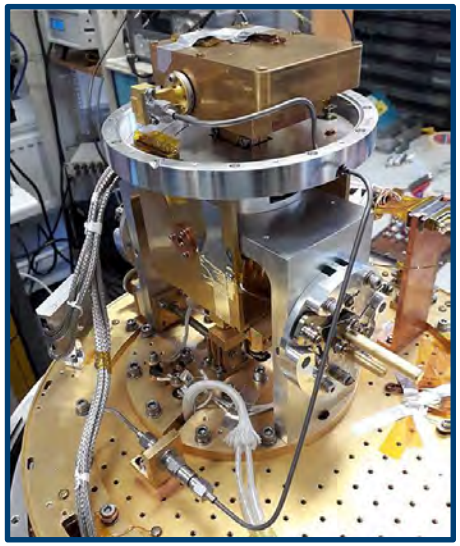
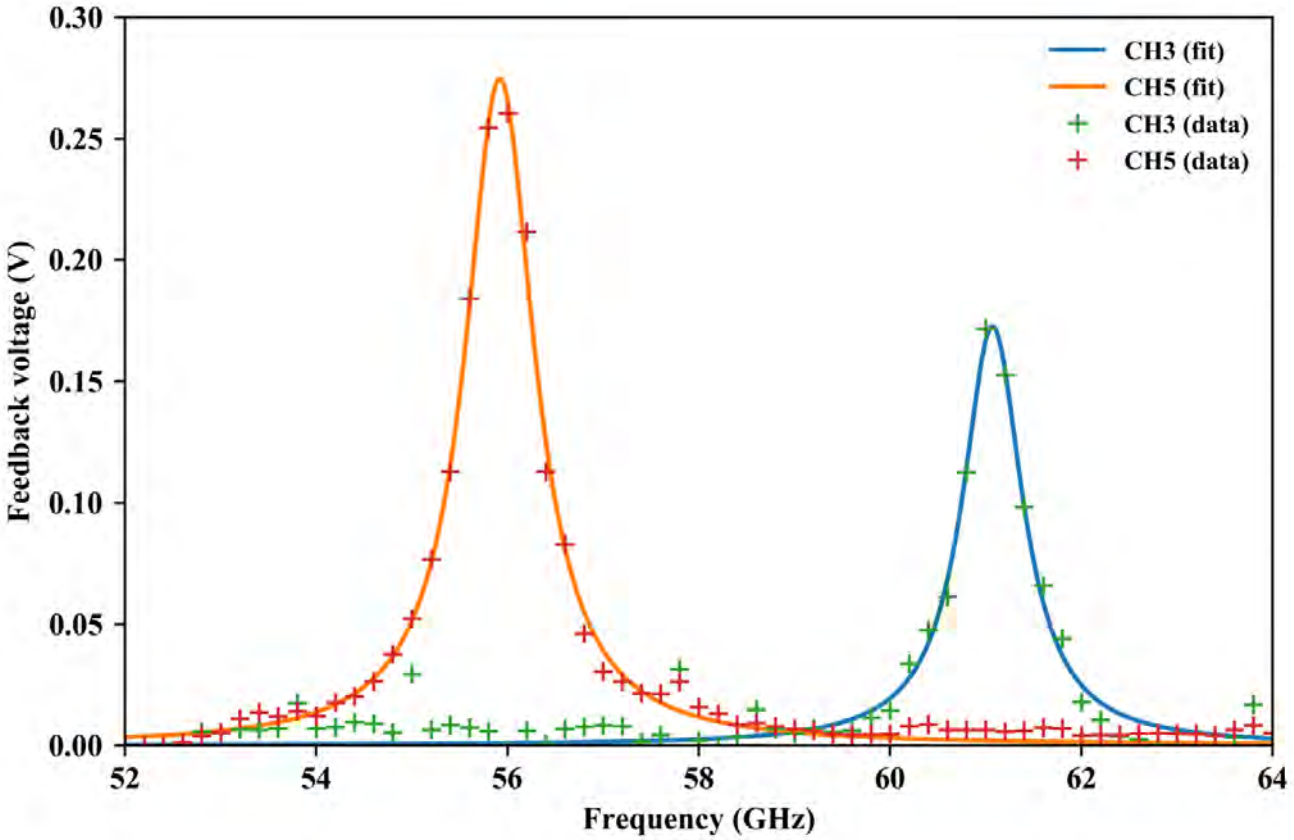
Measured performance: 1st generation LF chips







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Measured performance: 1st generation LF chips

Equivalent tests on new eLF and HF chips shortly…

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Future: Instrument concept study

- Strawman satellite mission concept – photon-noise limited hyperspectral sounding & ice-cloud studies (>200GHz). **Proposing more than 100 R=500 channels.**
- Aim to combine/enhance-on capabilities of MWS, MWI, ICI and legacy instruments in single instrument to offset cooler requirements.
- Will lead to technology roadmap and plan for demonstrators.
- Includes initial study of 300mK cooling chain for LEO. More generally useful for other technologies!
- **Very interested to hear about other possible applications… (particularly ground based)**

Conclusions

- Superconducting on-chip filterbank spectrometers are a promising technology for realising a next generation hyperspectral sounder.
- 1st generation LF devices (60GHz) demonstrated.
- 2nd generation LF devices and 1st generation HF devices (180GHz) fabricated and about to start testing – temperature and humidity sounding demonstrated.
- Instrument concept being developed to guide future development work.

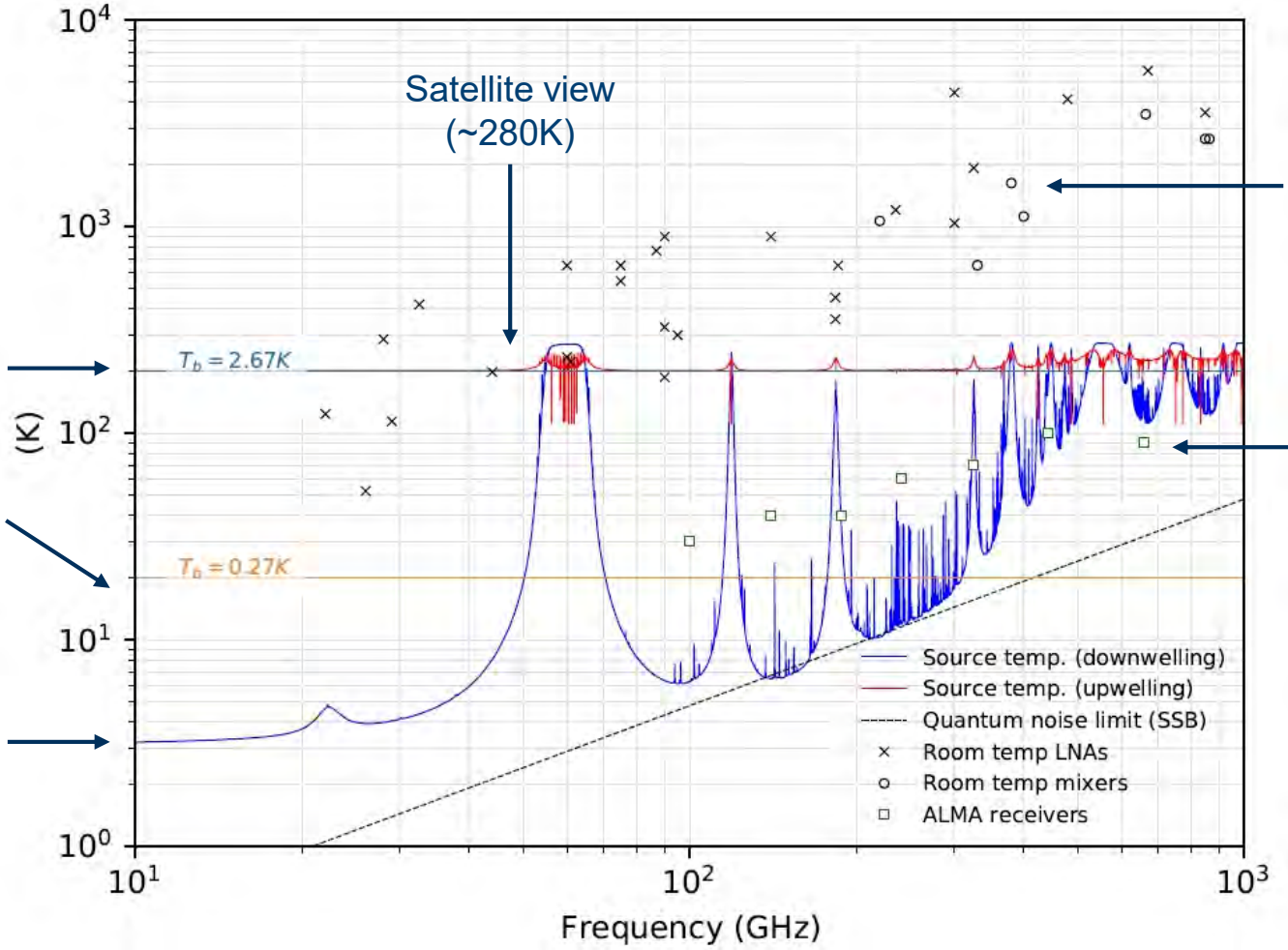
Acknowledgements & Further information

- **Thank you to CEOI for funding this work!**

- Papers on detector technology:
  - DOI: 10.1063/5.0002984 (or https://arxiv.org/abs/2001.08947)
  - DOI: 10.1117/12.2564383
- Papers on potential science performance:
  - DOI: 10.1117/12.2500516

Chris Thomas (cnt22@cam.ac.uk)

Additional content: Sensitivity comparison



Other advantages: size and instantaneous bandwidth