Technology Development Needs for the Inflation Probe

Detector arrays & focal-plane coupling –

Harvey Moseley

Multiplexing -

Kent Irwin

- What are the key immediate areas for development?
- Where is the technology heading in the near term (<2015) and mid-term (>2015)?

The Inflation Probe Technology Roadmap

Technology	Priority	Timescale	Candidates	TRL
Detector Arrays	**High**	**Sub-orbital experiments**	**TES+SQUID+Antenna** **HEMT / MMIC**	**4-5**
Optics	Medium	Sub-orbital experiments	Polarization modulators AR coatings	2-5
Coolers	Low	Develop for space	Passive+mechanical+sub-K	3-9
Advanced Arrays		Develop for simplified space implementation. Connects to X-ray, far-IR and optical astronomy	MKID+RF resonator TES+RF resonator	3

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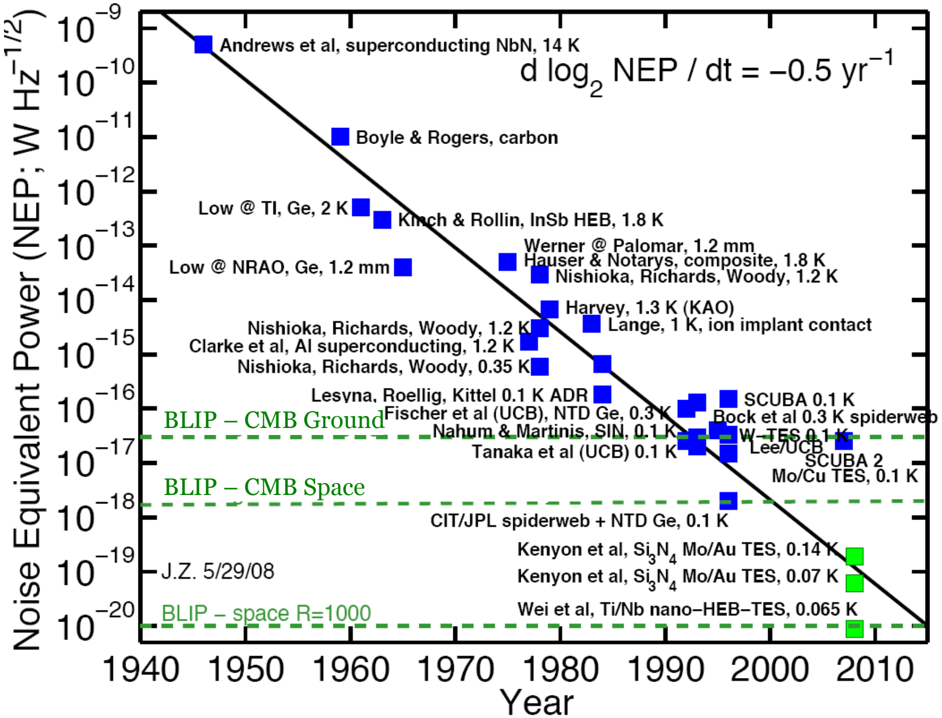
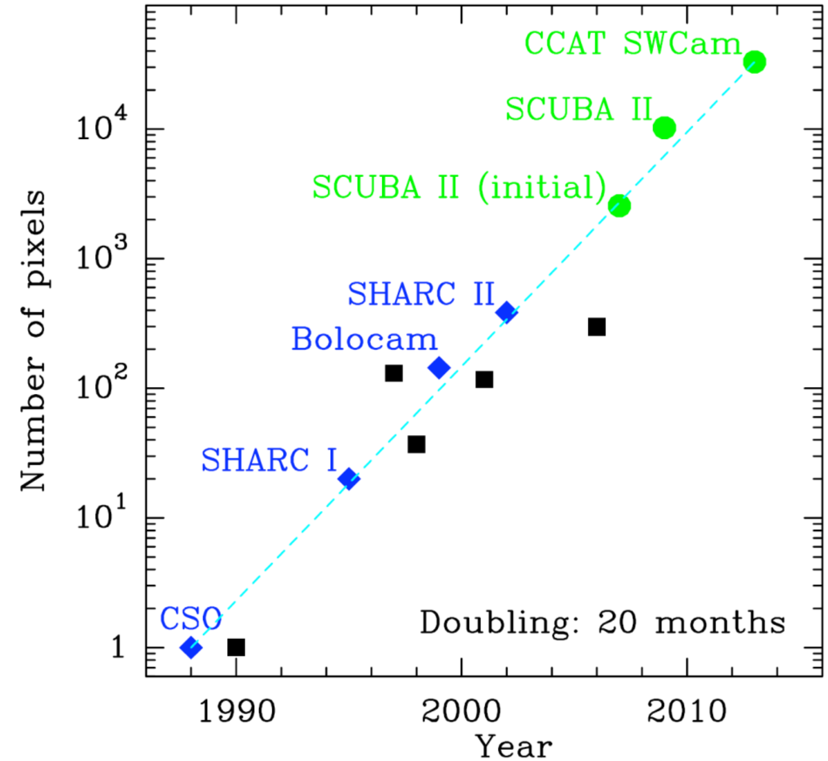
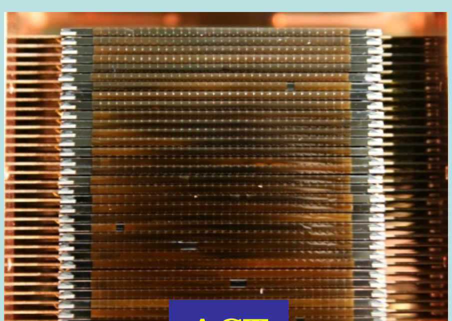
Kilopixel TES arrays a reality – *clear path to a satellite*



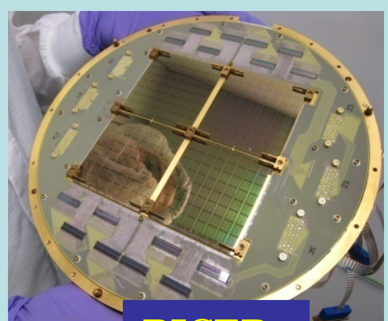


- Rapid progress in arrays
- Development synergy with far-IR and X-ray astronomy

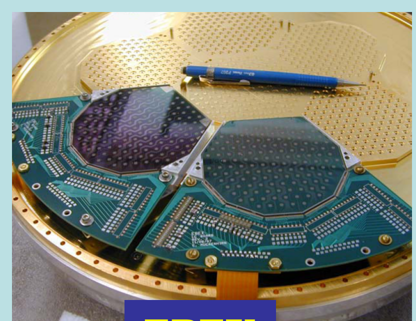
Technology & Sub-Orbital Program



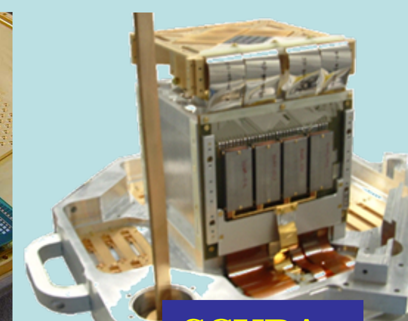
ACT



BICEP2

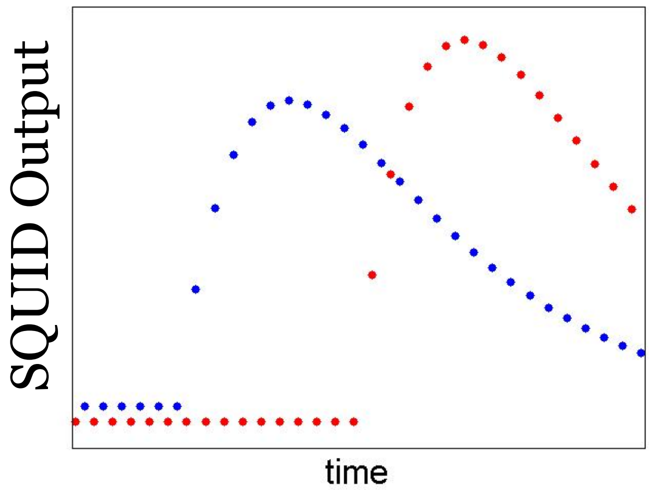


EBEX

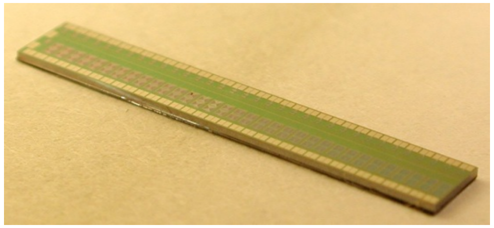


SCUBA2

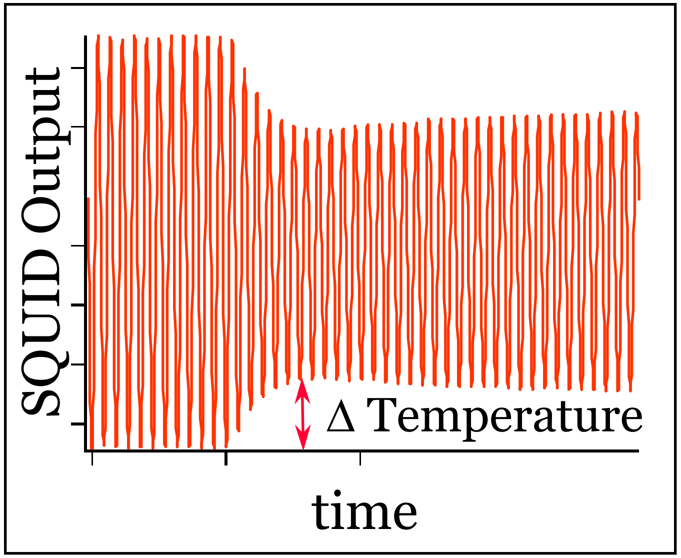
Multiplexed readout: two maturing techniques



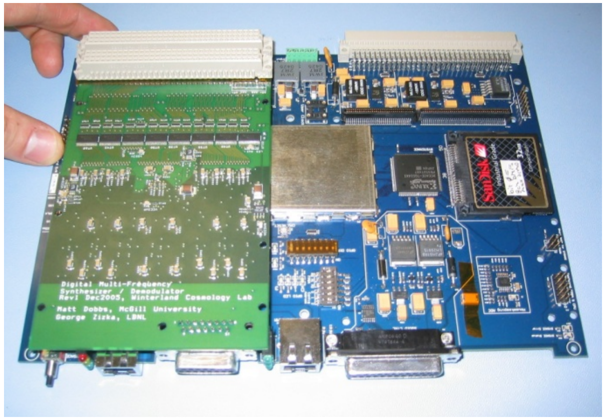
Time division (**TDM**): different pixels at different times



TDM SQUID switches



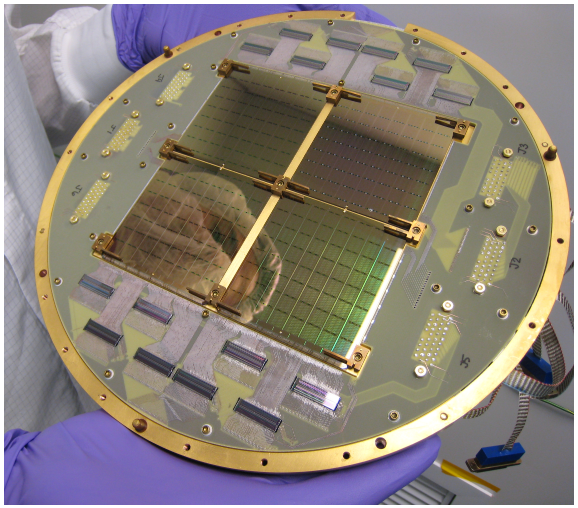
Frequency division (**FDM**): different pixels at different frequencies



Room-temperature electronics for FDM

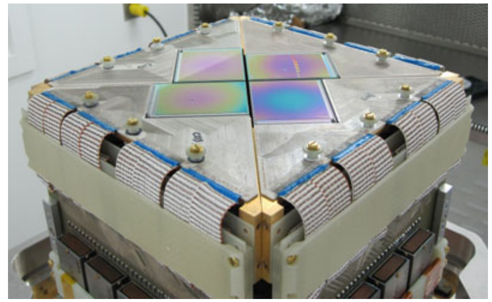
A few of the TES arrays in the field

BICEP-2: 512

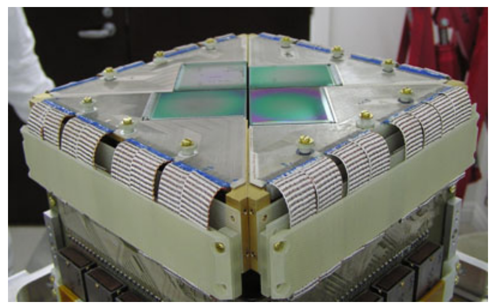


SCUBA-2: 10,000

450 um

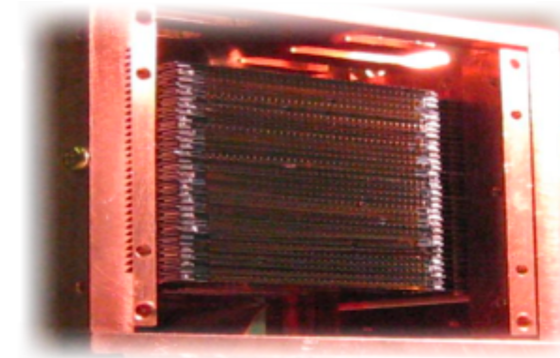


850 um

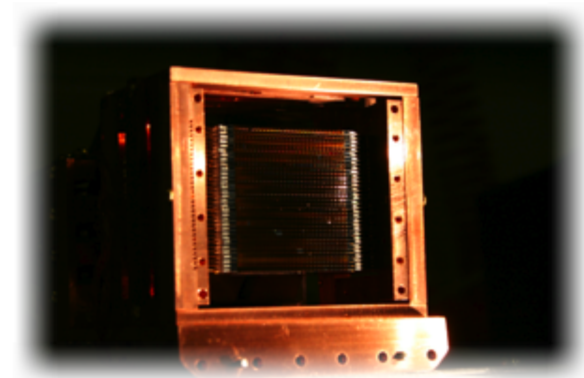


ACT-SZ: 3,000

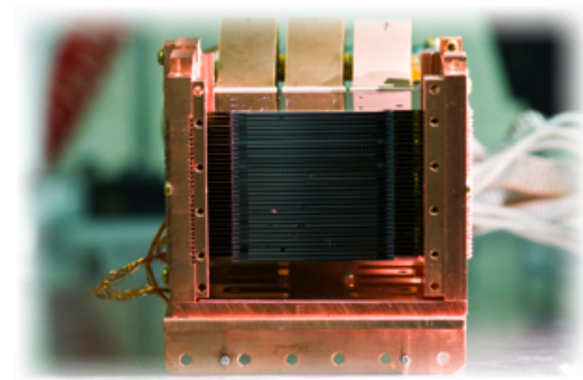
148 GHz



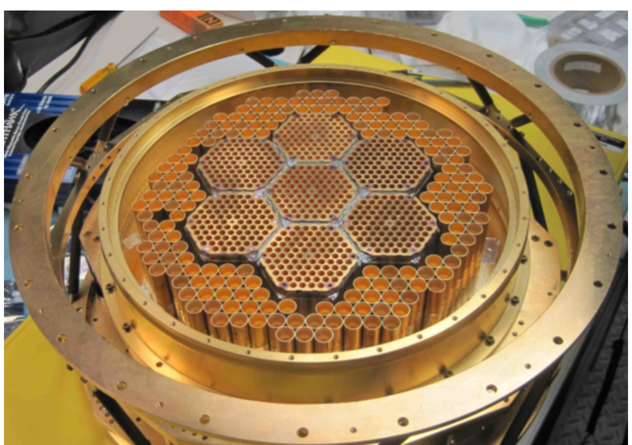
218 GHz



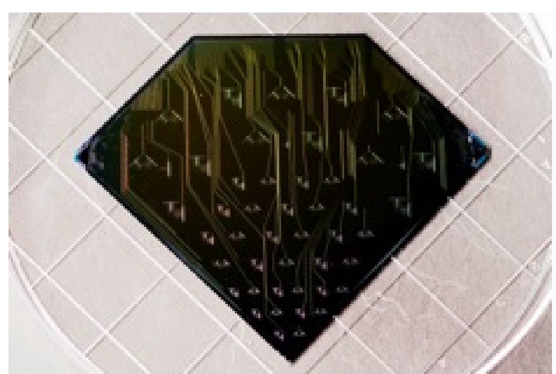
277 GHz



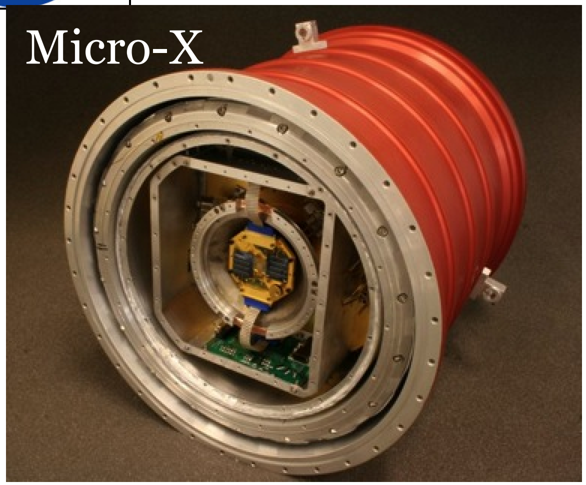
SPTpol: 1,536



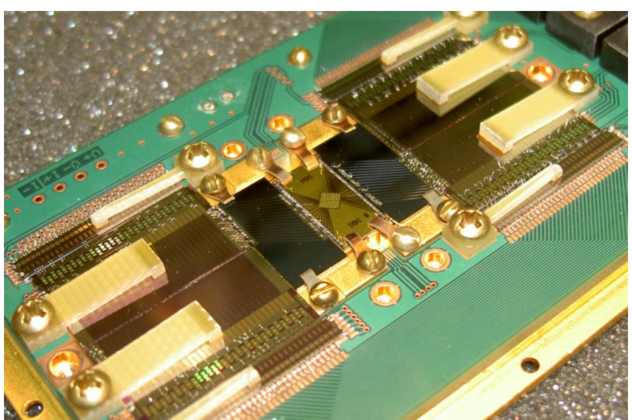
POLARBEAR: 1,274

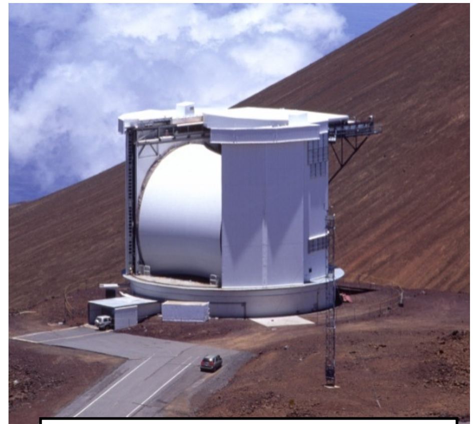


Synergy with x-ray and submillimeter

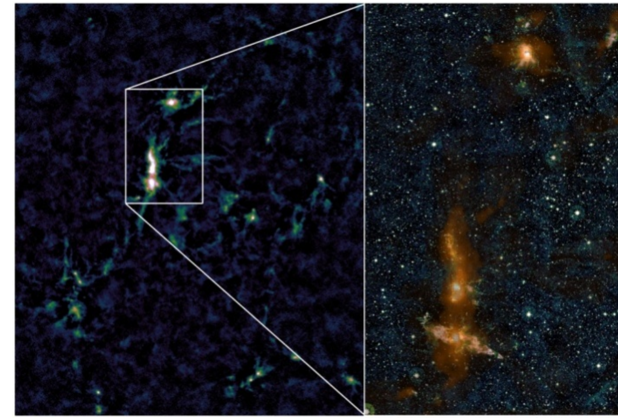


TES thermometer and readout are similar to x-ray sensors needed for present sounding rocket experiments (Micro-X) and future satellite missions





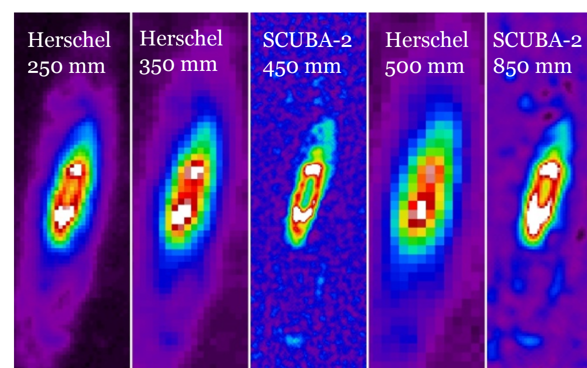
James Clerk Maxwell Telescope



The DR21 star forming region. The left hand panel shows the SCUBA-2 850 mm image while the right-hand panel is a close up region where the 850 mm data has been overlayed on a UKDISS infrared image (Image credit:JAC)

TES thermometer and readout also leverage the development of submillimeter cameras, such as SCUBA-2 at the JCMT

NGC7331 at 5 wavelengths. The central ring-link structure is clearly visible in the submillimeter dust emission. (Image credit: JAC, Herschel KINGFISH consortium)

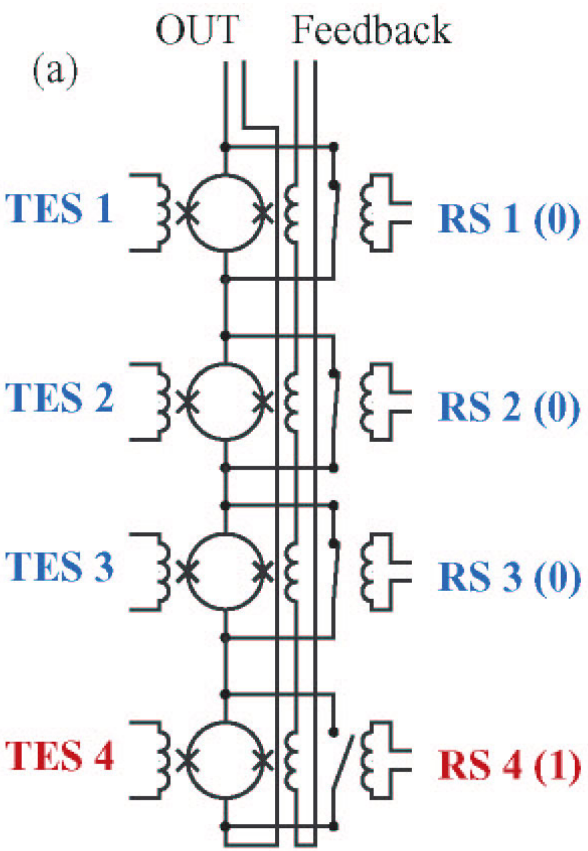


Technology needs: TDM

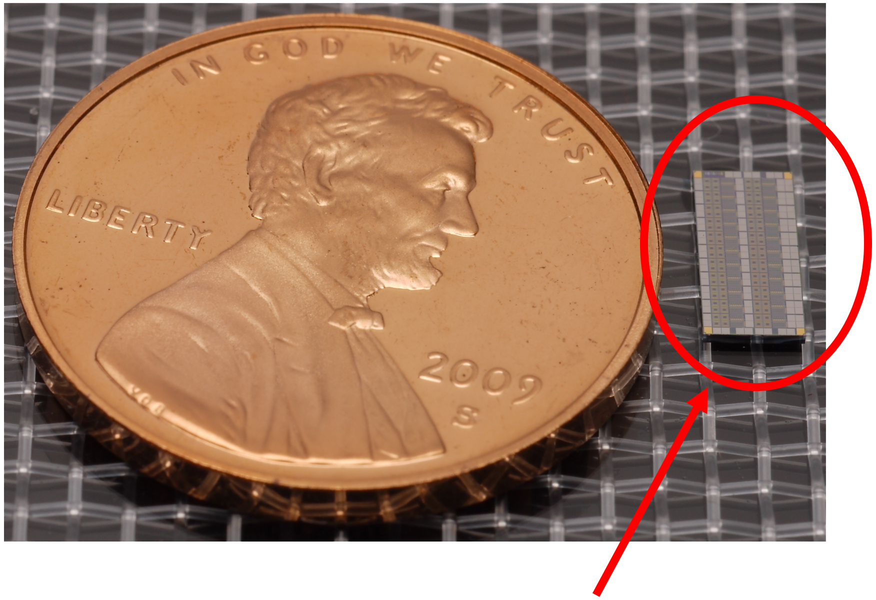
TDM broadly used on ground: ACT, SCUBA-2, BICEP-2, Keck Array, SPIDER, ACTpol, CLASS, PIPER, GISMO, ABS…

- TDM Maturation
  - Demonstration in a balloon-borne environment (SPIDER)
  - Reduction in wires
    - EPIC-IM 4K TDM: 5,280 wires, current generation
    - Next-generation flux-addressed TDM: <1,000 wires for EPIC-IM
  - Reduction in cryo power load:
    - EPIC-IM 4K TDM: 1.9 μW at cold stage
    - Next-generation flux-addressed TDM: < 100 nW (20× lower)
  - Reduction in room-temp electronics power:
    - EPIC-IM TDM requires 10× lower room temp. electronics power
    - Next-generation TDM will provide ~3× power reduction; the rest comes from lower power components in SPIDER electronics.
    - Need to develop flight-qualified electronics

Flux-address TDM (next generation)



Flux-address TDM



Next-generation flux-address MUX

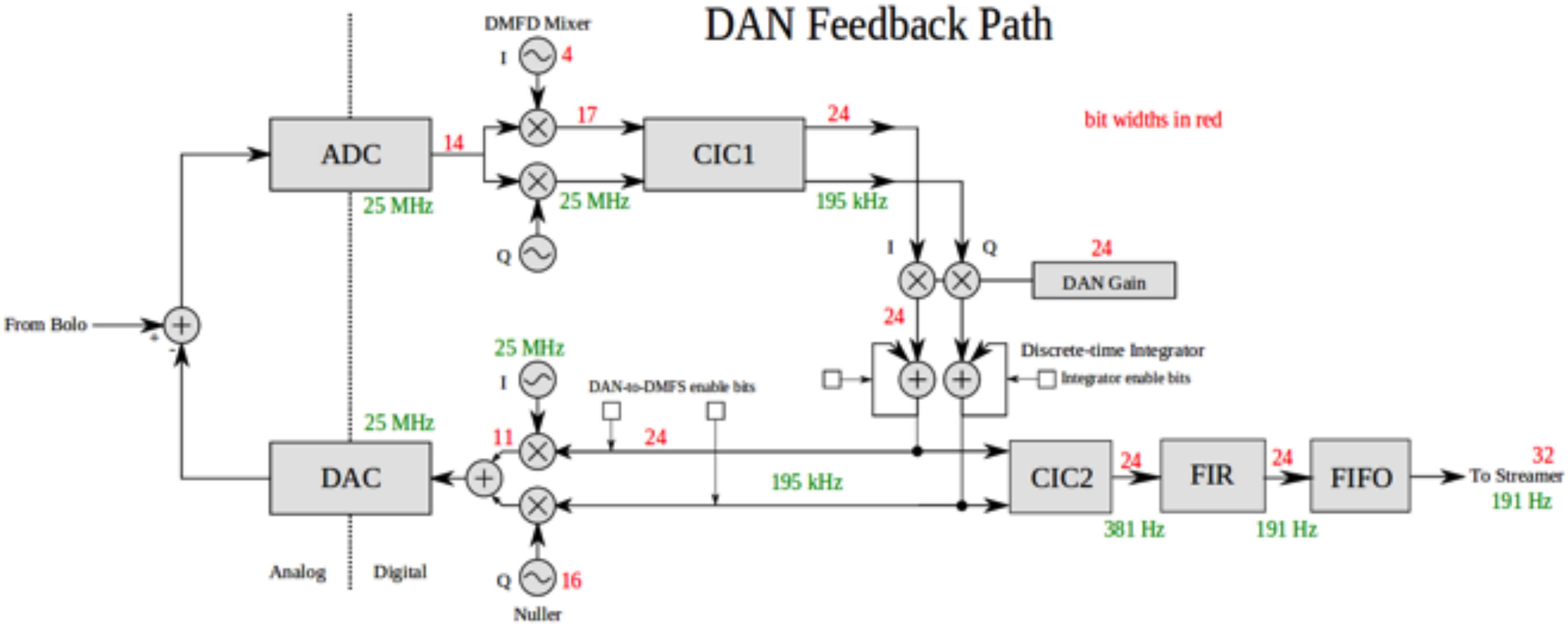
- Excellent uniformity; 100× mux factor
- 5× reduction in wires for EPIC-IM
- 20× reduction in cold power dissipation
- ~3× reduction in room-temperature electronics power from high mux factor
- On-sky demonstration needed

Technology needs: FDM

FDM broadly used on ground: APEX-SZ, SPT, SPTpol, EBEX, POLARBEAR…

- FDM Maturation
  - Full demonstration in a balloon-borne experiment (EBEX)
  - Reduction in wires
    - Full EPIC-IM 4K FDM requires 32× MUX factor (EBEX is 16 ×)
    - Next generation FDM 32× in development; 64× goal.
  - Baseband feedback / Digital active nulling
    - Required for the long wires to room temperature in EPIC-IM
  - Reduction in room-temp electronics power:
    - EPIC-IM TDM requires 10× reduction in electronics power (from the 250 mW/detector in EBEX).
    - Digital FDM provides power reduction

Digital active nulling (next generation FDM)



- SQUID feedback loop is digital, but localized to the vicinity of the carriers
- Eliminates wire length restrictions between cryogenic stages
- Deploy for SPT 3rd Generation, POLARBEAR2
- Canadian Space Agency funded development at McGill

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Advanced array technology: rf-resonators

- Detectors read out with high-Q microwave resonators can have higher multiplex factors, enabling larger arrays (~100 kpixels).
- Advanced, flight-qualified, low-power room-temperature microwave electronics must be developed

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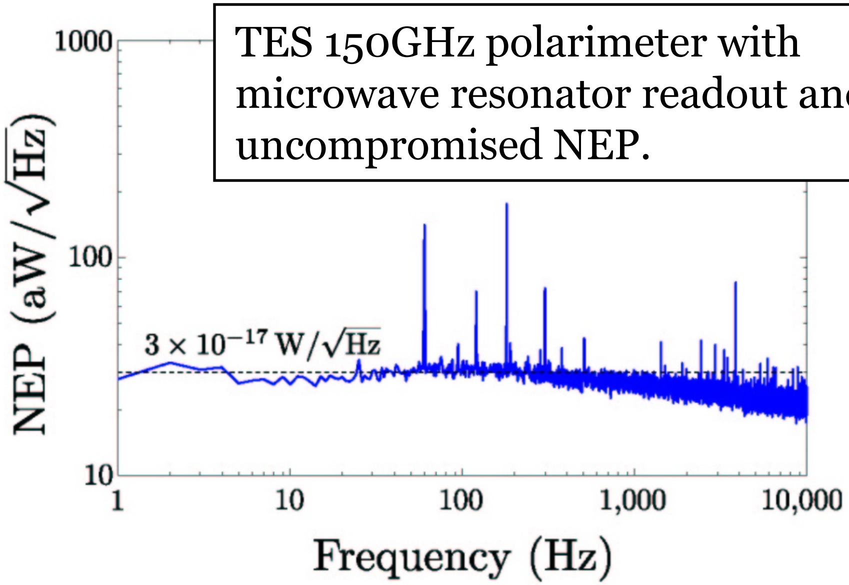
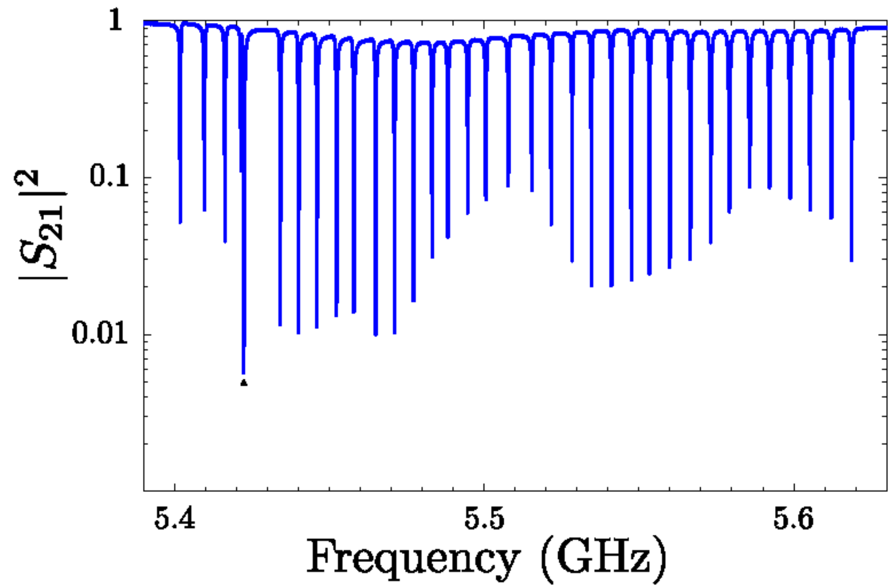
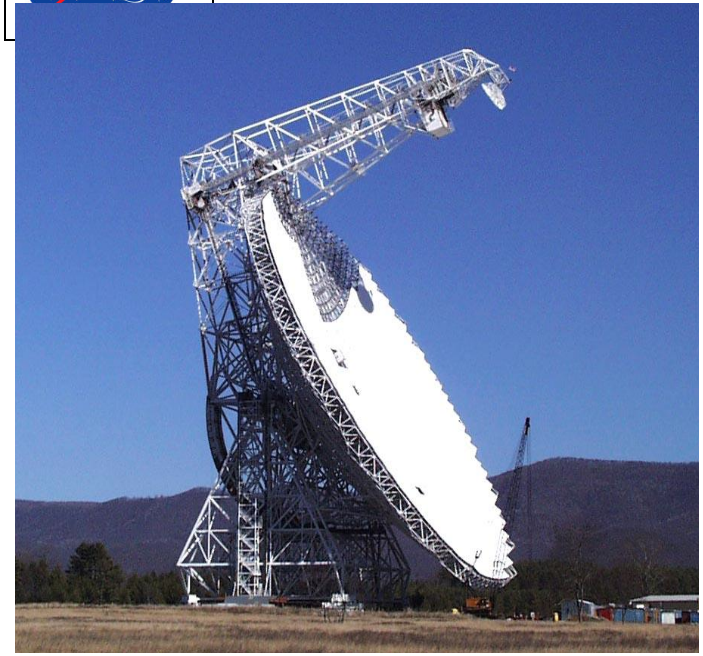
TES 150GHz polarimeter with microwave resonator readout and uncompromised NEP.

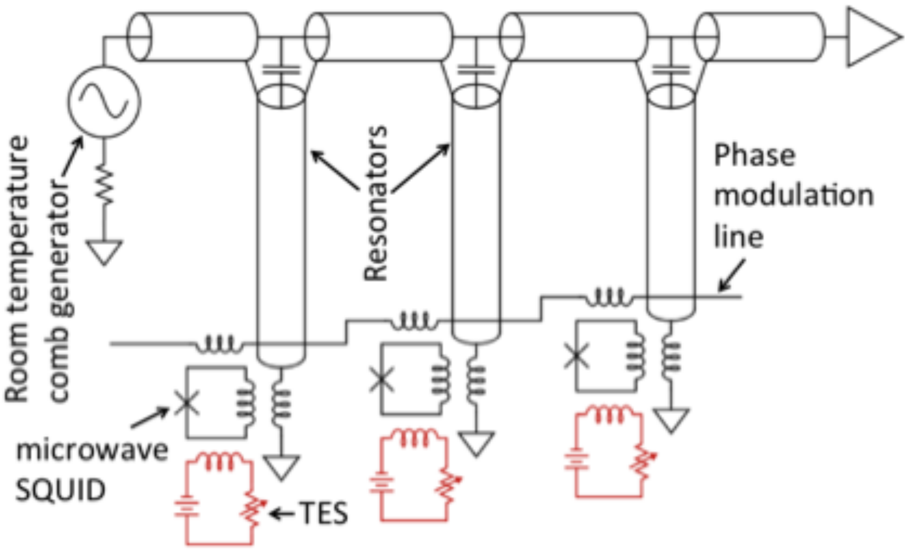


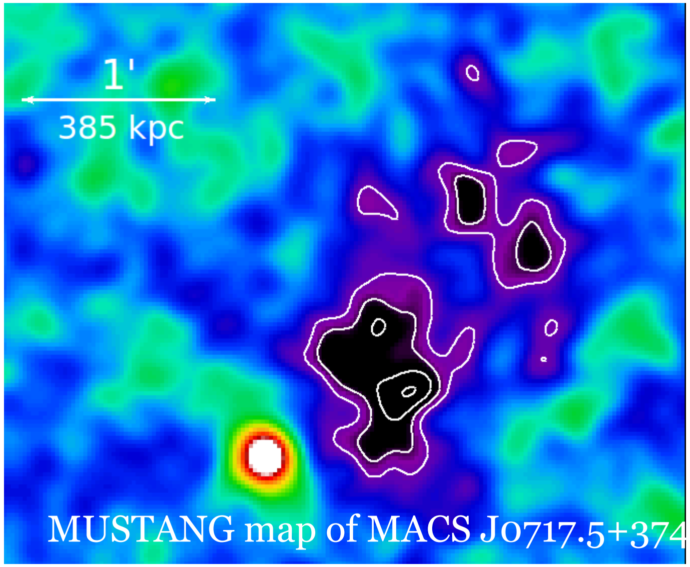


1. In the **microwave kinetic inductance detector (MKID)**, the rf resonator itself is the sensor. Improved pixel sensitivity needs to be demonstrated in the CMB.
2. TESs can also be read out with rf resonators using quantum-limited amplifiers, with noise as good as TDM and FDM. Now being deployed in 400-channel MUSTANG-2.

Rf-resonator TES: MUSTANG 2







MUSTANG map of MACS J0717.5+374

Mroczkowski 2012

- High-resolution Sunyaev-Zel'dovich imaging of galaxy clusters at 90 GHz
- For 100 m Green Bank Telescope
- 9" resolution, 4.5' fov
- ~400 feedhorn-coupled TES polarimeters
- 20x improvement in sensitivity over MUSTANG
- First microresonator-coupled TES array on sky

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