CCAT: An Introduction

Jonas Zmuidzinas, Caltech
on behalf of the CCAT consortium

CCAT: quick facts

- 25m diameter
- 20’ to 1 degree FOV
- 12 μm rms surface rms
- 0.2 – 2 mm wavelength range
- Cerro Chajnantor, Chile (5600 m)
- University consortium
  - Cornell, Caltech/JPL, Colorado, Canada, Cologne (& Bonn)
  - Will likely include US community participation, through NSF
- Key personnel
  - CCAT Board Chair: Jack Burns, Colorado
  - Director: Riccardo Giovanelli, Cornell
  - Project Manager: Jeff Zivick, Cornell
  - Project Engineer: Steve Padin, Caltech

A brief history of CCAT

- October 2003
  - Cornell & Caltech/JPL hold a workshop to discuss the case for a large, wide-field (25 m) submm telescope
- 2004
  - Cornell & Caltech sign MOU to perform feasibility study
  - hire PM and DPM
- 2005: Site selection & characterization
- January 2006
  - Feasibility study review, ~ $100M cost estimate
- 2007-2010
  - Add partners (Colorado, Canada, Germany)
  - Continue technical work
- 2010
  - Astro2010 top-ranked medium-scale project
  - $120M to $140M cost estimate
- 2011: Entering detailed engineering design phase
- 2013: Start construction
- 2018: First Light

Early mm-wave astronomy

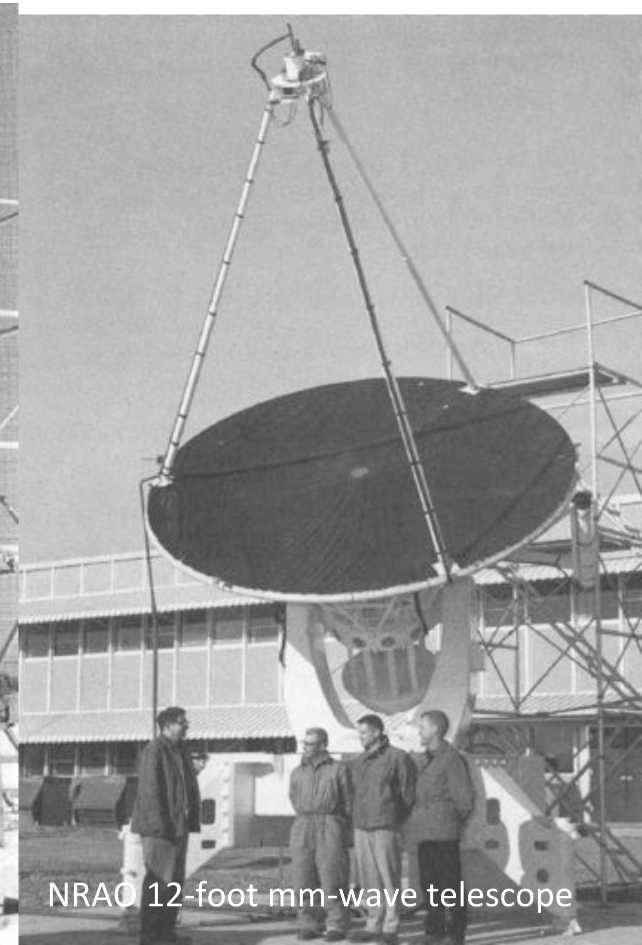
- 1961: Frank Low invents the Ge bolometer
- 1963: Sun, Moon, bright planets

TABLE

N.R.A.O. MICROWAVE THERMAL-DETECTION RADIOMETER

Center frequency =250 GC (λ =1.2 mm)
Bandwidth = ~35 per cent
ΔT_{min} =0.015 °K, rms for τ =10 seconds
1.2 mm Efficiency =25 per cent
dc Bolometer Characteristics:
- T_0 =2.0 °K
- R_0 =7 by 10^6 Ω
- G =0.85 μ watt/°K
- τ_B =12 ms
- f_0 =10 c/s
- Volume =1.2 by 1.0 by 0.36 mm^3
- S =1.3 by 10^6 volts/watt
- Noise =5 by 10^{-8} volt/cs, rms
- N.E.P. =4 by 10^{-14} watt

NRAO 5-foot mm-wave telescope



NRAO 12-foot mm-wave telescope

Low & Tucker, 1968

VOLUME 21, NUMBER 22 PHYSICAL REVIEW LETTERS 25 NOVEMBER 1968

CONTRIBUTION OF INFRARED GALAXIES TO THE COSMIC BACKGROUND*

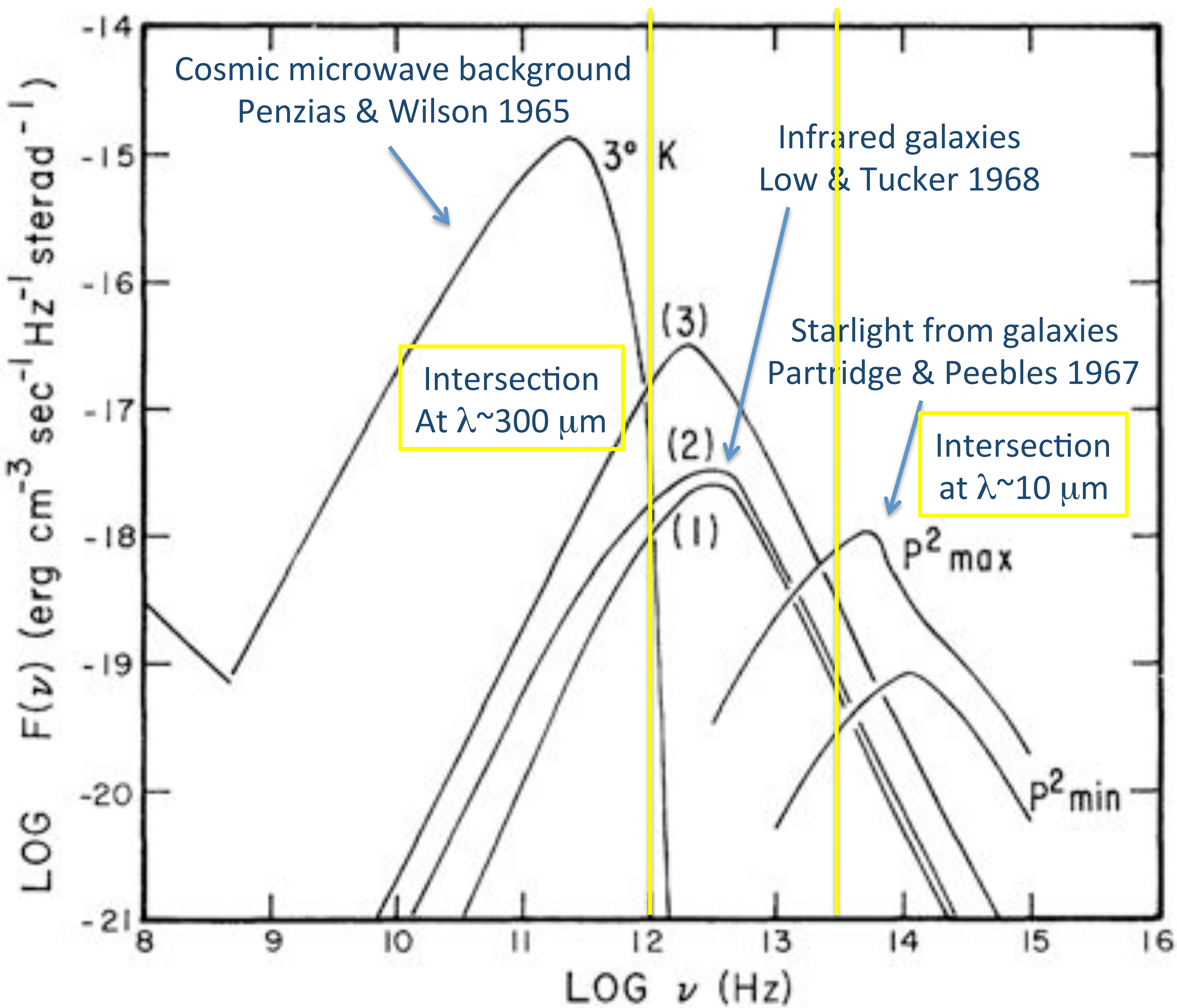
Frank J. Low
Department of Space Science, Rice University, Houston, Texas,
and Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona

and

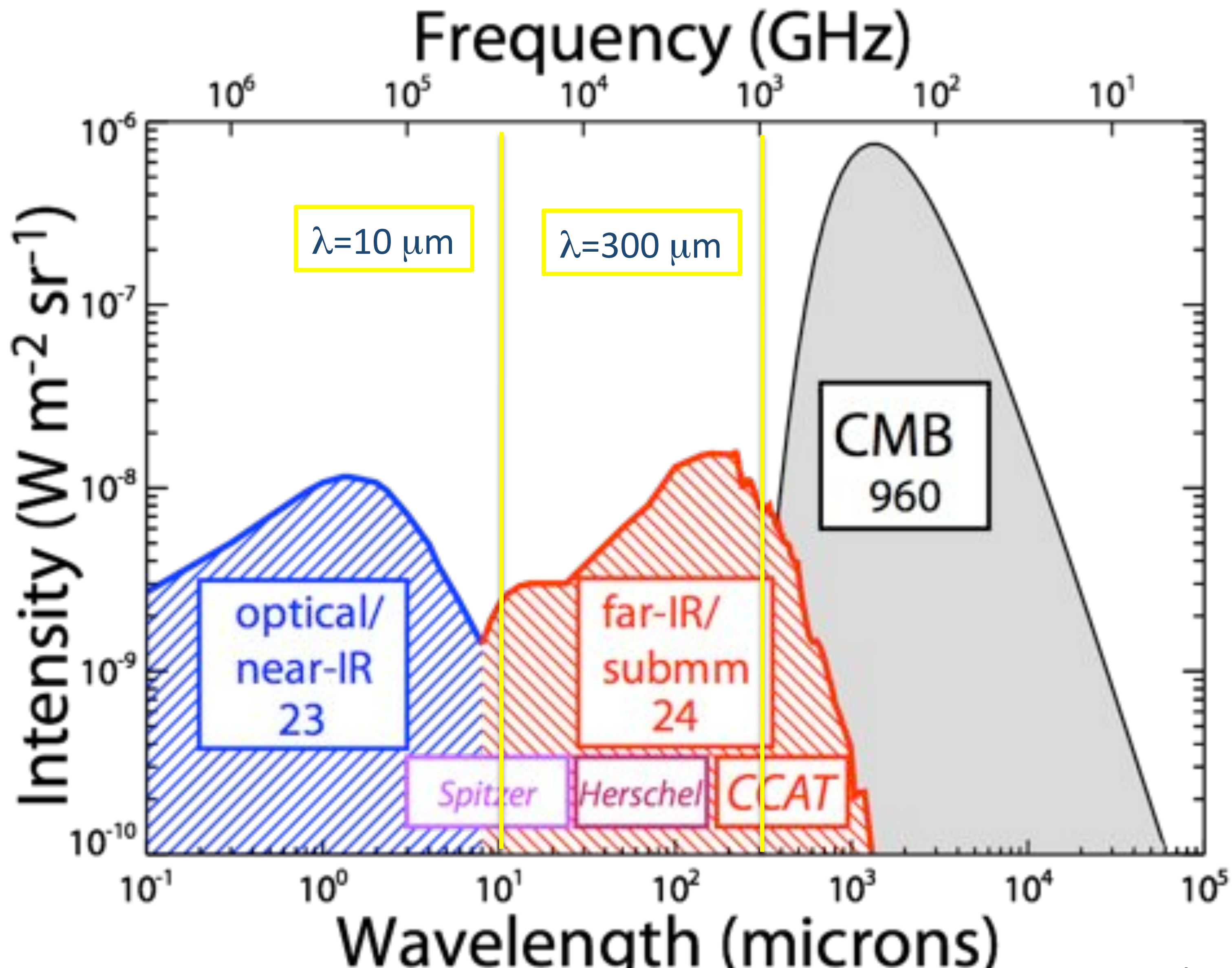
Wallace H. Tucker
Department of Space Science, Rice University, Houston, Texas

(Received 12 July 1968)

The far-infrared background due to a superposition of infrared galaxies of the type recently observed is computed. It is shown that these galaxies contribute an amount of energy to the universe roughly equal to that radiated by the other galaxies and produce a far-infrared background peaking beyond 50 μ. It is likely that they account for most of the observed extragalactic radio background but not the 3°K microwave background.

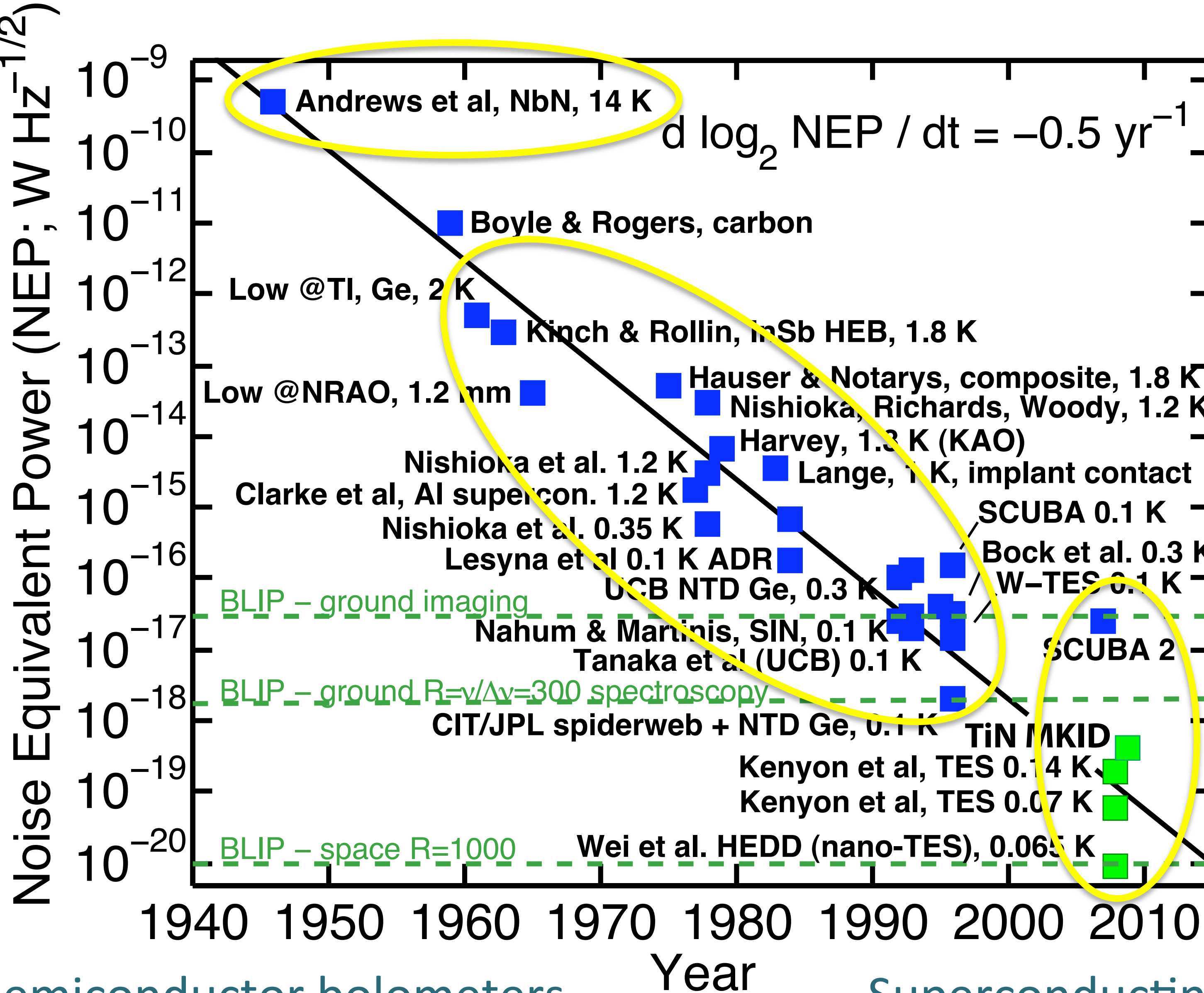

Cosmic microwave background
Penzias & Wilson 1965
Infrared galaxies
Low & Tucker 1968
Starlight from galaxies
Partridge & Peebles 1967
Intersection
At λ~300 μm
Intersection
at λ~10 μm
3° K
(3)
(2)
(1)
P² max
P² min
LOG F(ν) (erg cm⁻³ sec⁻¹ Hz⁻¹ sterad⁻¹)
LOG ν (Hz)
-14
-15
-16
-17
-18
-19
-20
-21
8
9
10
11
12
13
14
15
16

Light in the universe



Dole et al. 2006

Richards' First Law

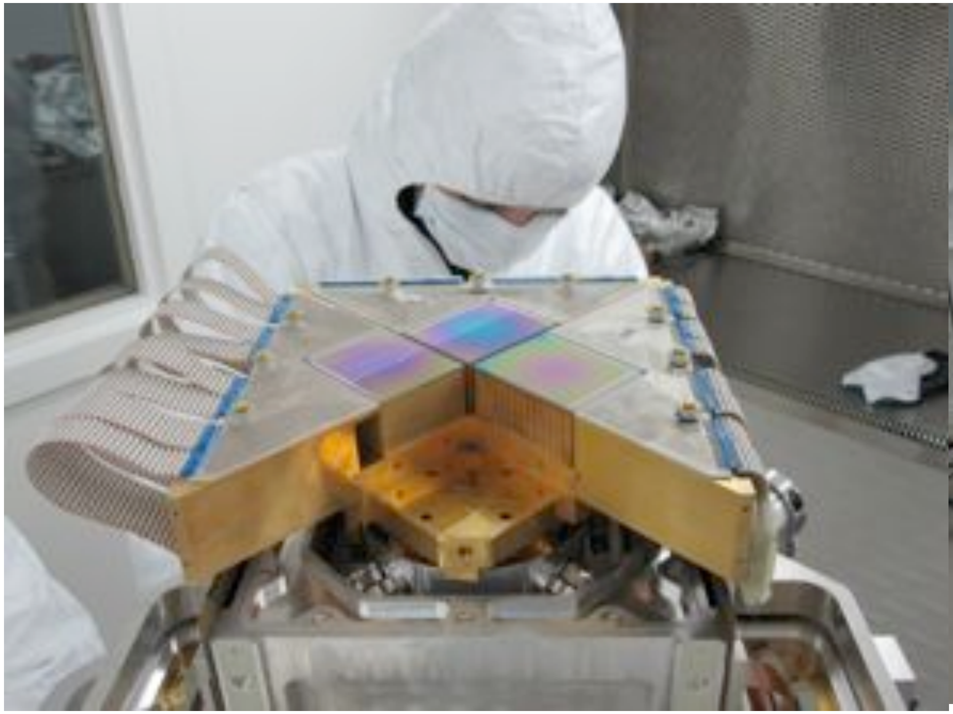


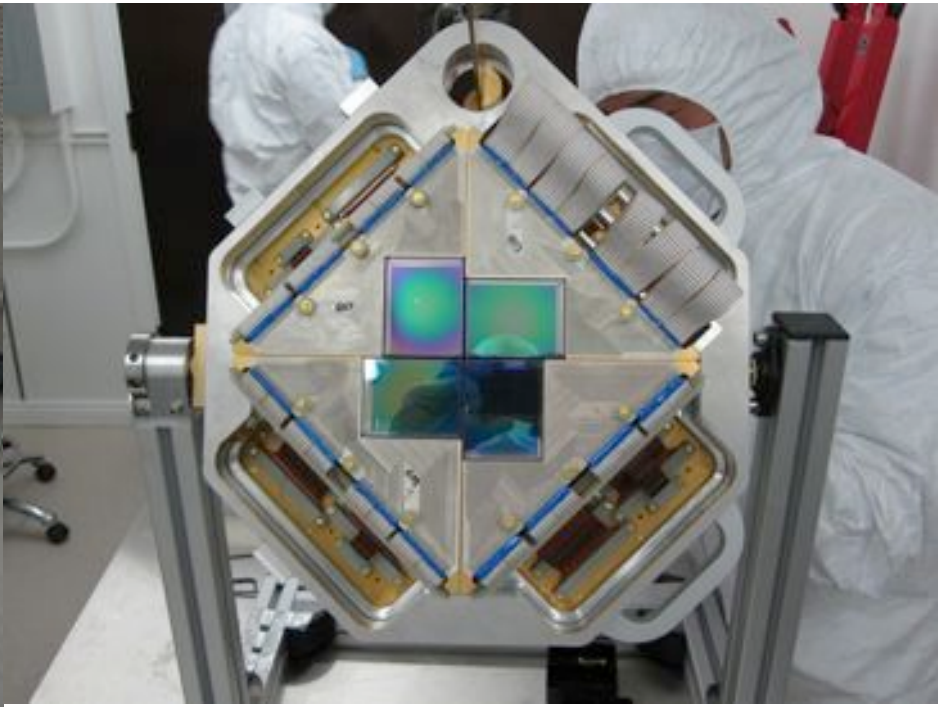
Semiconductor bolometers

Superconducting detectors

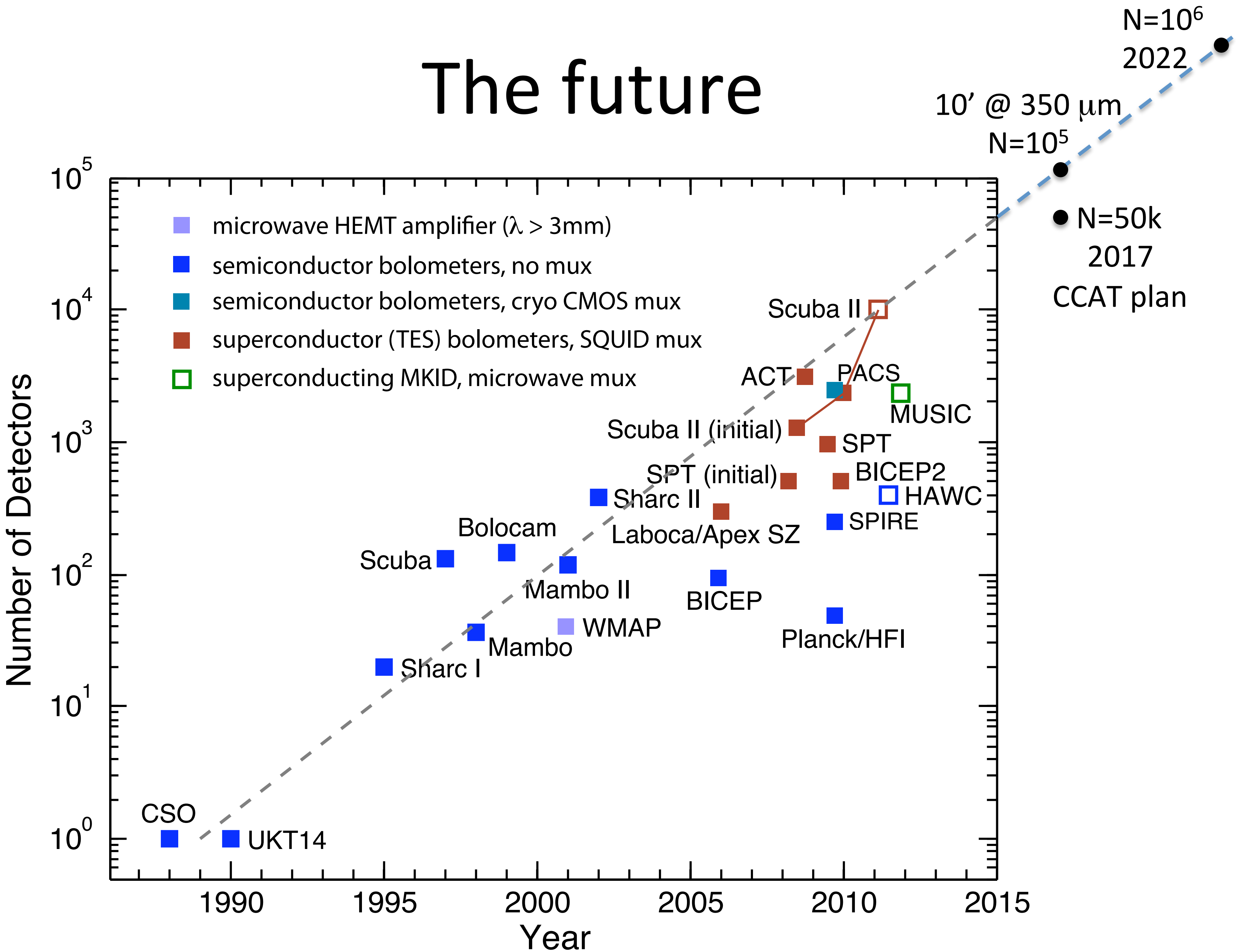
Herschel ATLAS SDP

The present: SCUBA 2 with 10k pixels





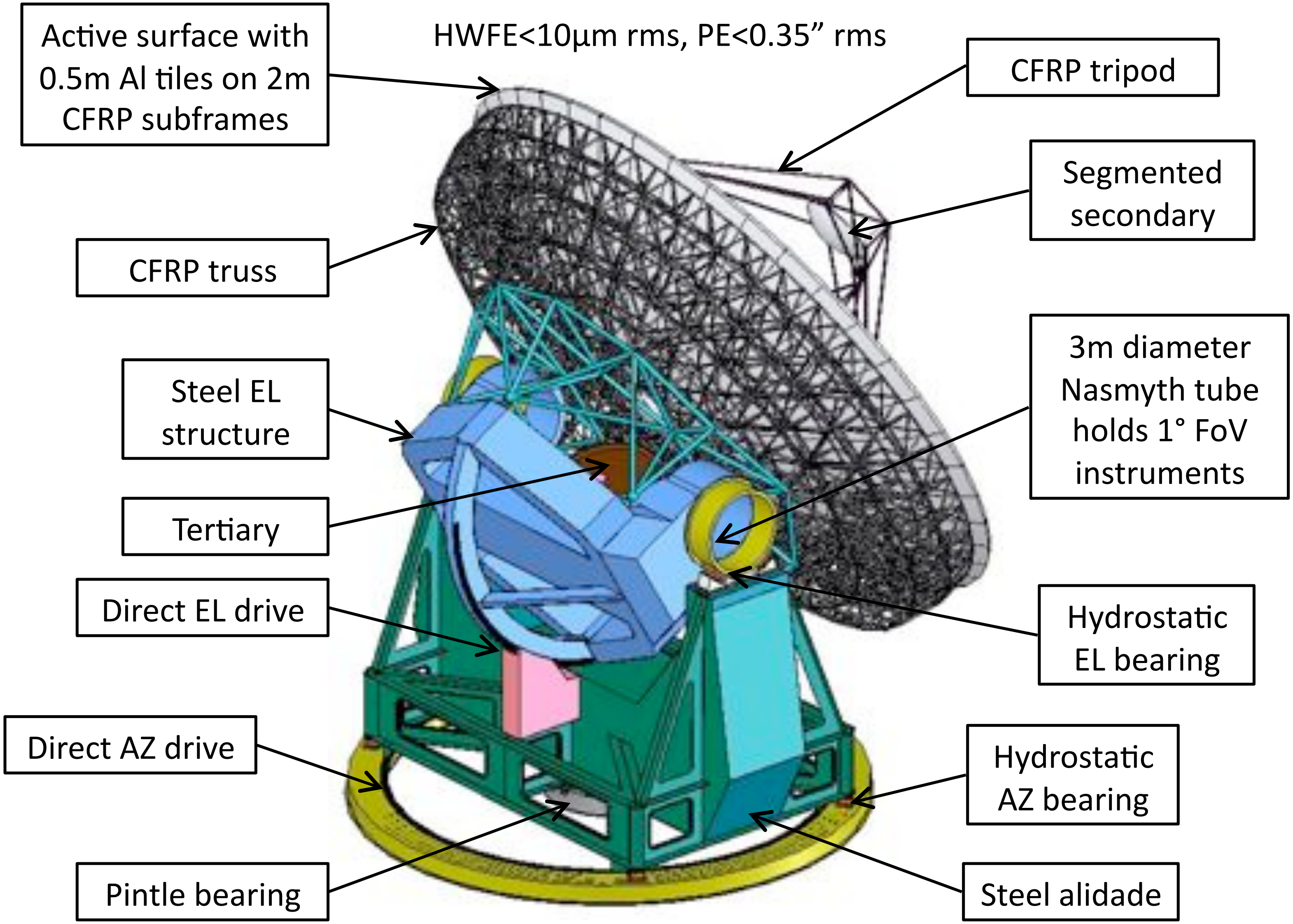
The future



N=10^6
2022
10′ @ 350 μm
N=10^5
N=50k
2017
CCAT plan
microwave HEMT amplifier (λ > 3mm)
semiconductor bolometers, no mux
semiconductor bolometers, cryo CMOS mux
superconductor (TES) bolometers, SQUID mux
superconducting MKID, microwave mux
Number of Detectors
10^5
10^4
10^3
10^2
10^1
10^0
Scuba II
ACT
PACS
MUSIC
Scuba II (initial)
SPT
SPT (initial)
BICEP2
HAWC
Sharc II
SPIRE
Laboca/Apex SZ
Bolocam
Scuba
Mambo II
BICEP
WMAP
Planck/HFI
Mambo
Sharc I
CSO
UKT14
1990
1995
2000
2005
2010
2015
Year

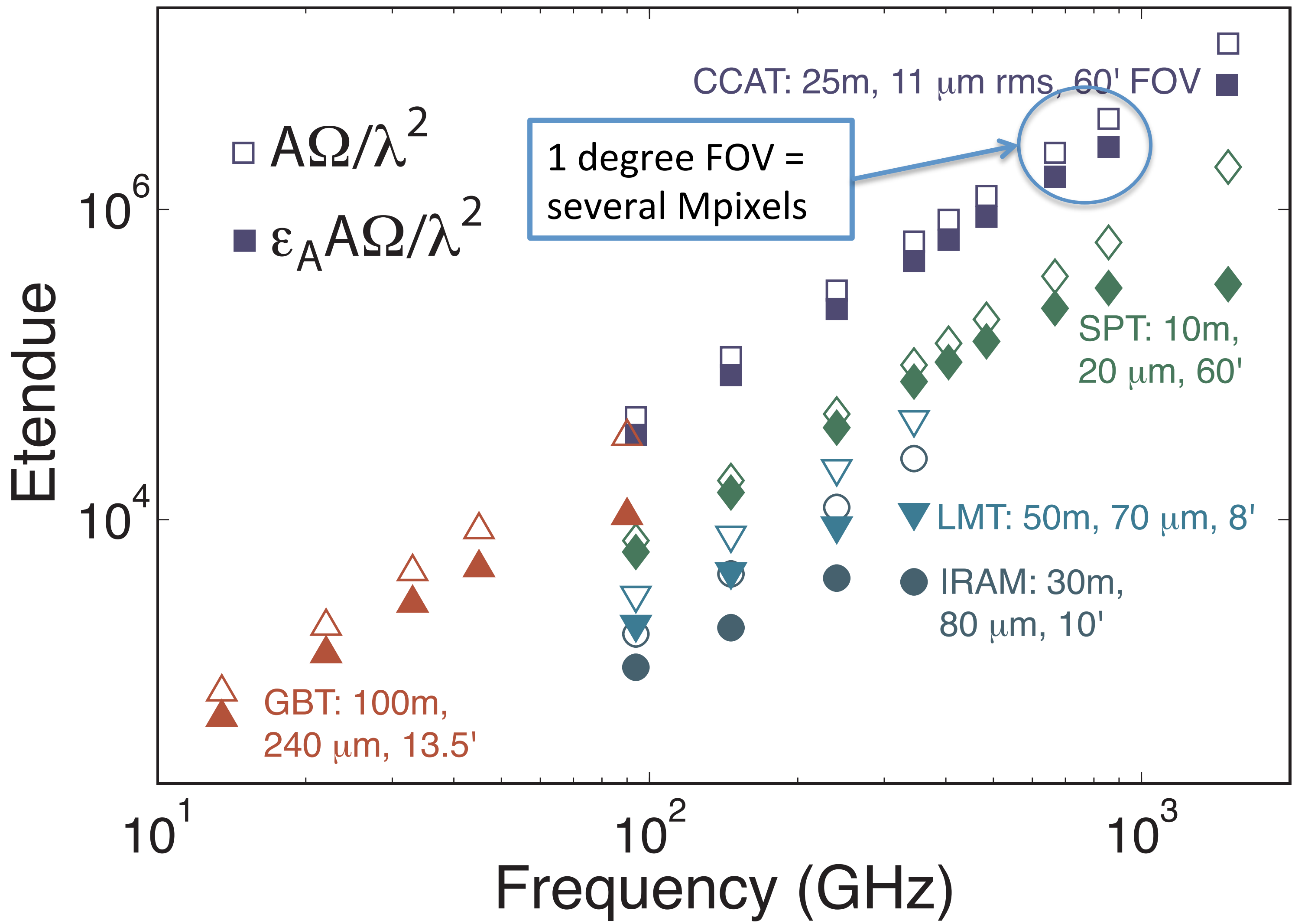
Telescope concept

HWFE<10μm rms, PE<0.35" rms

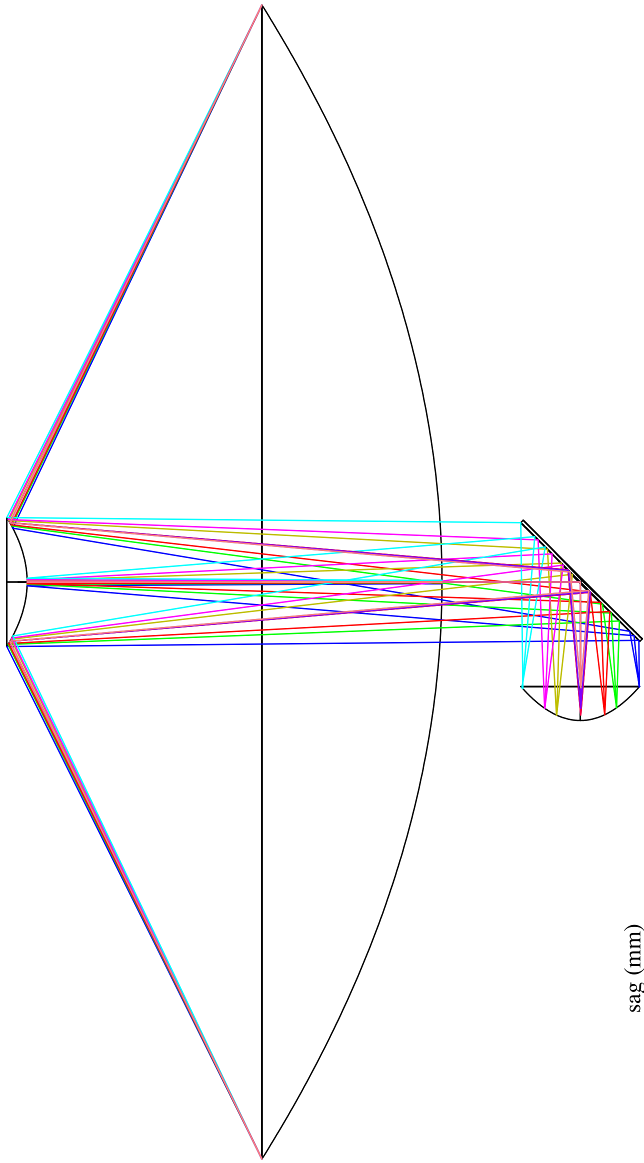


Credit: S. Padin

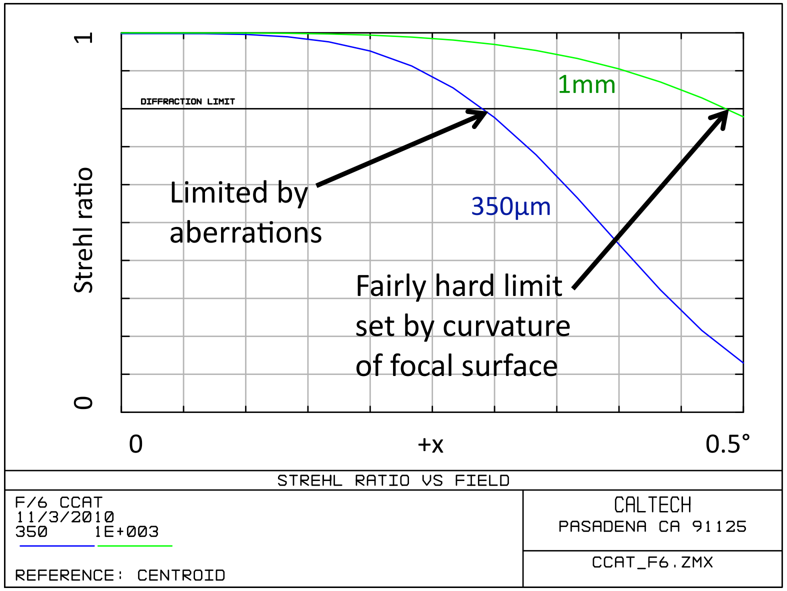
CCAT's wide field in context

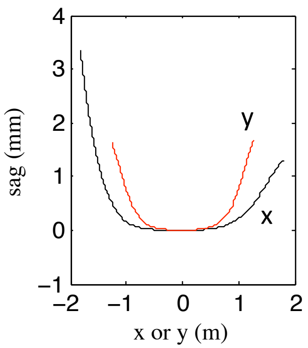


Field of view



Strehl ratio vs. field angle for basic RC telescope

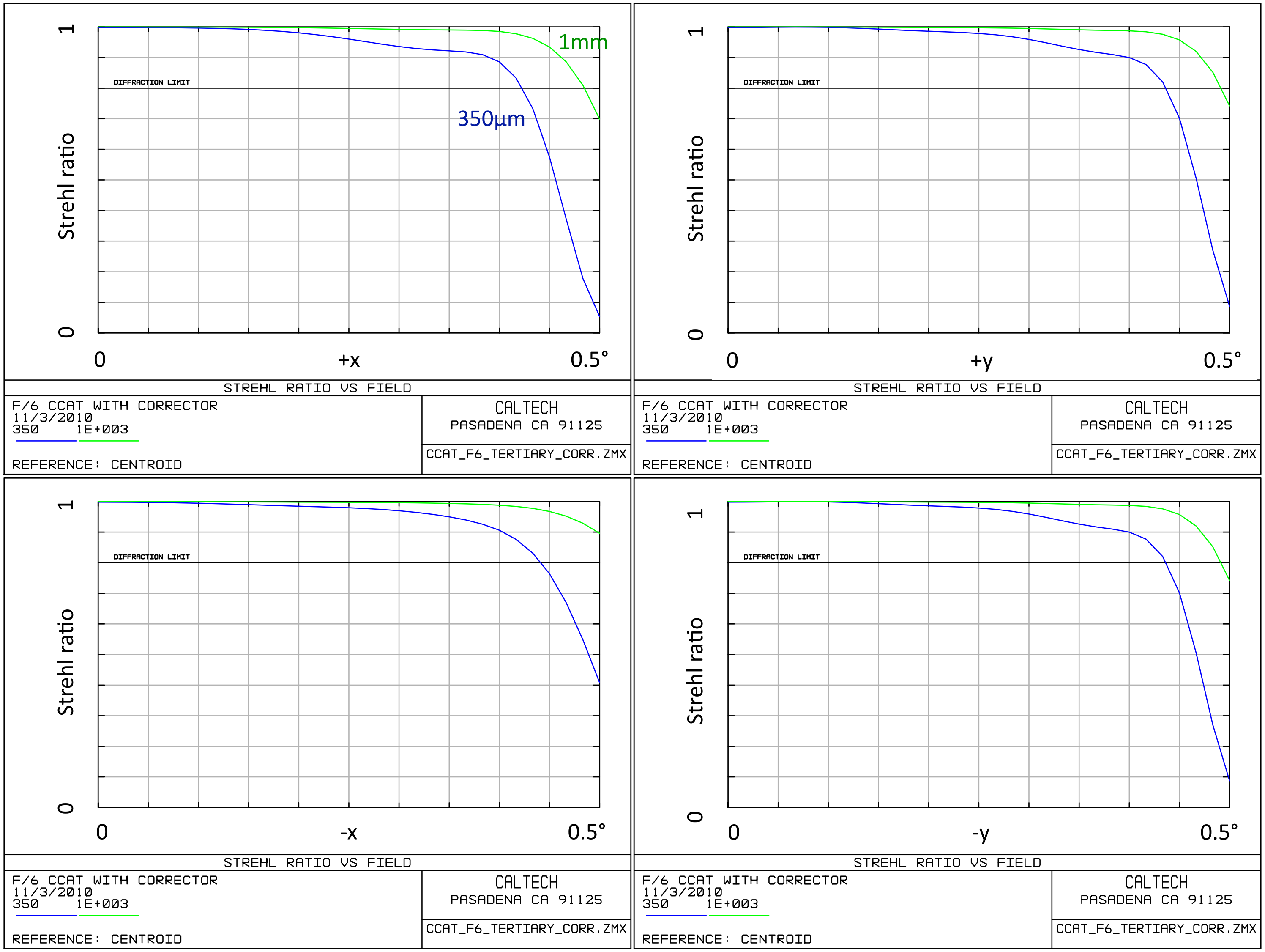




Tertiary profile to maximize FoV

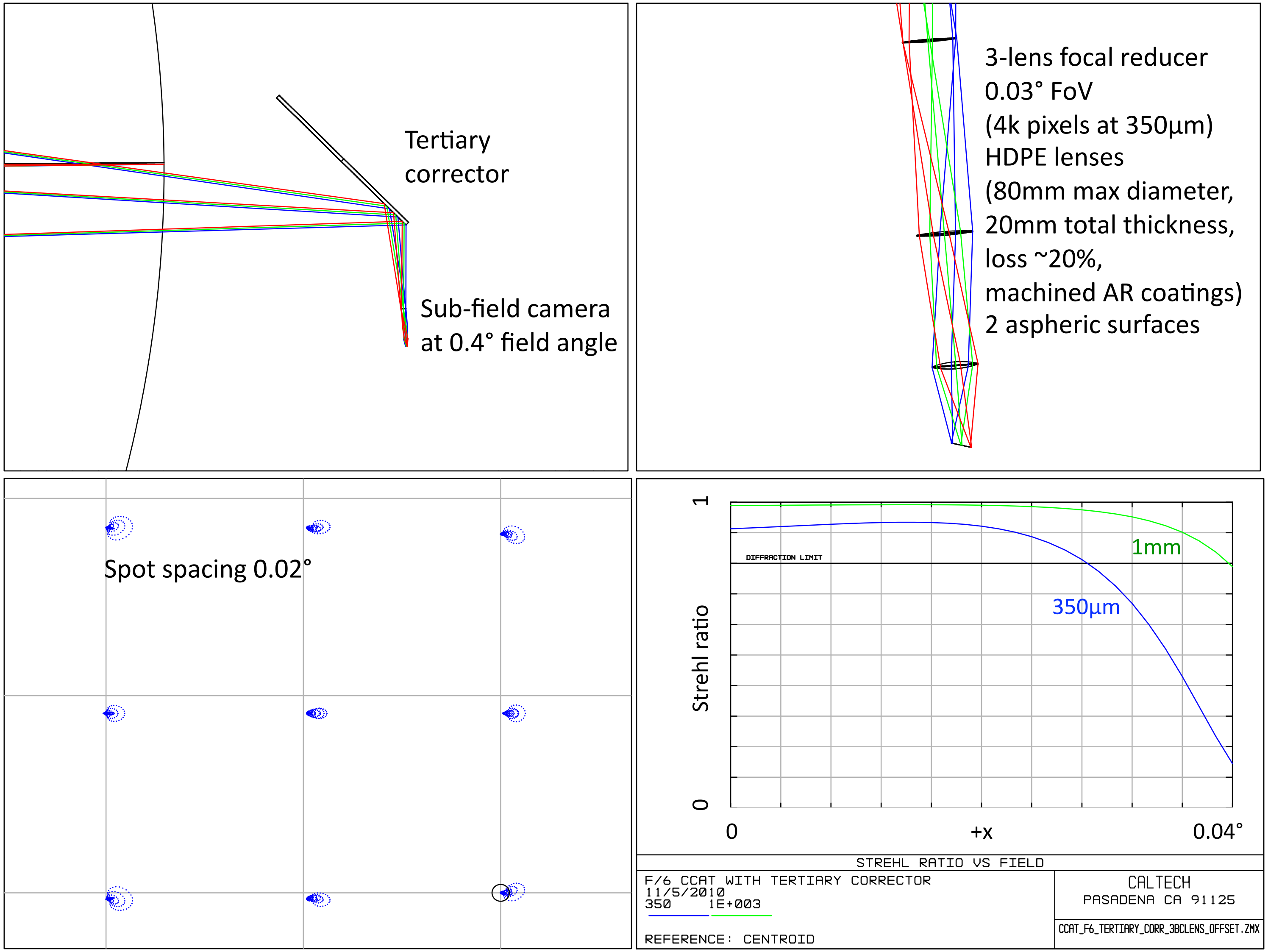
Credit: S. Padin

Strehl ratio vs. field angle with tertiary corrector



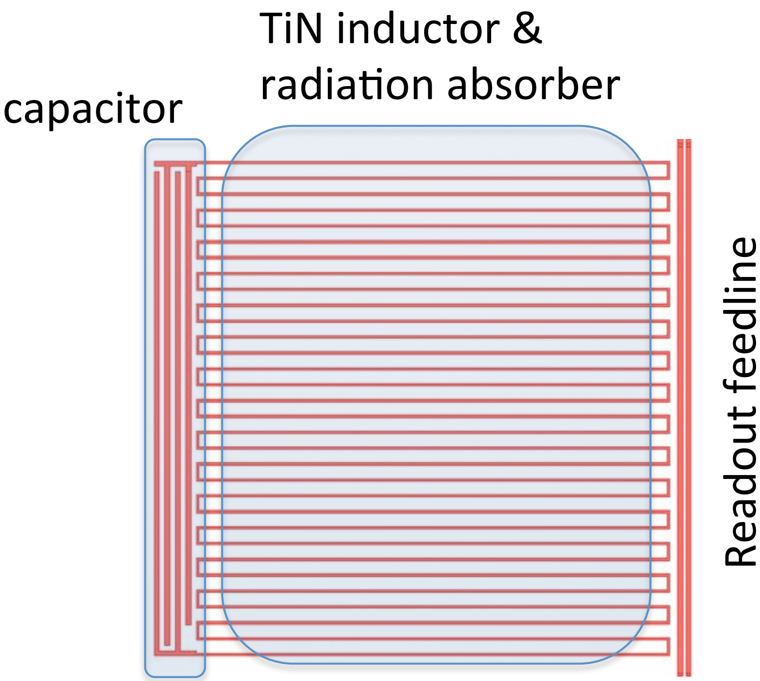
Credit: S. Padin

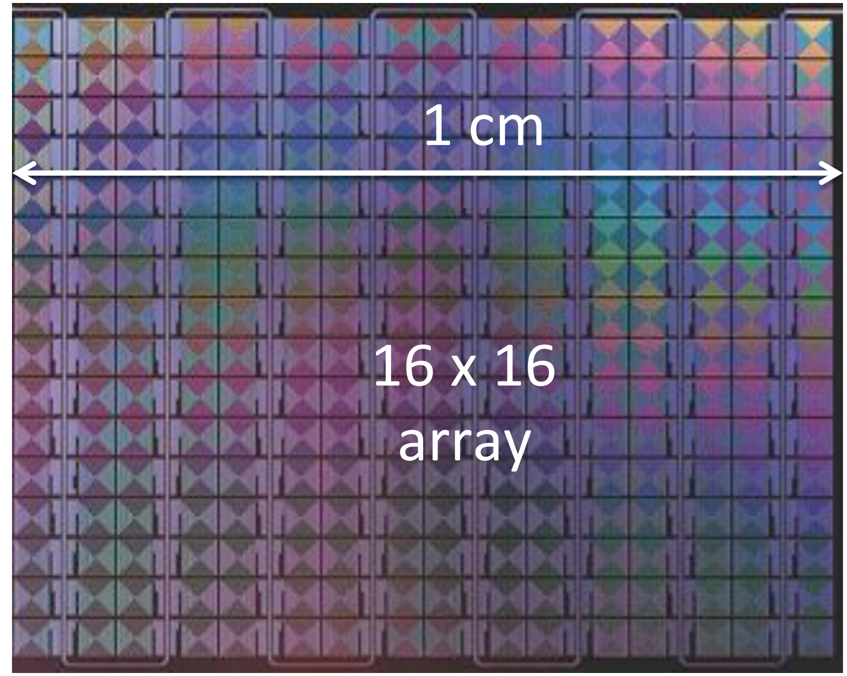
Camera relay with small HDPE lenses

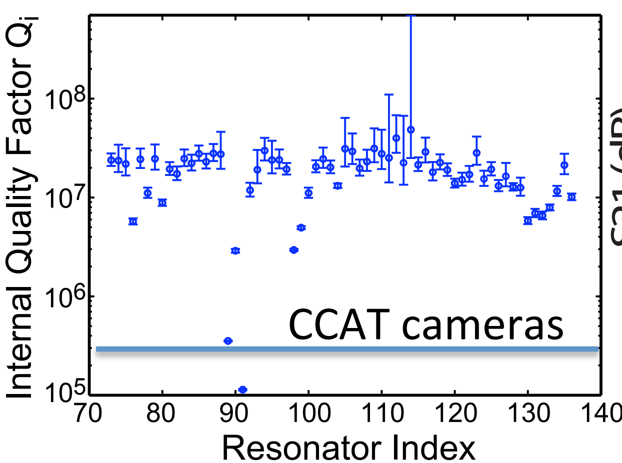


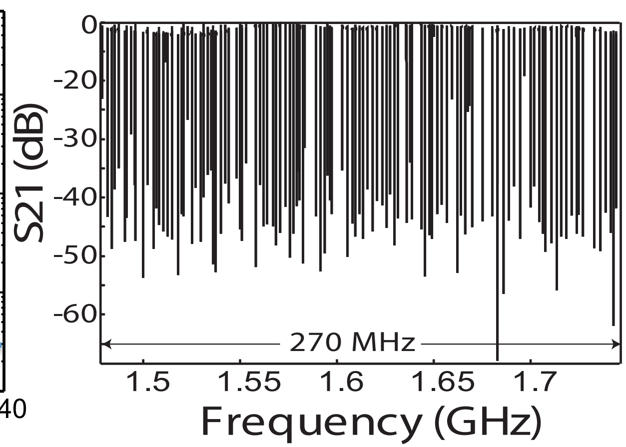
Credit: S. Padin

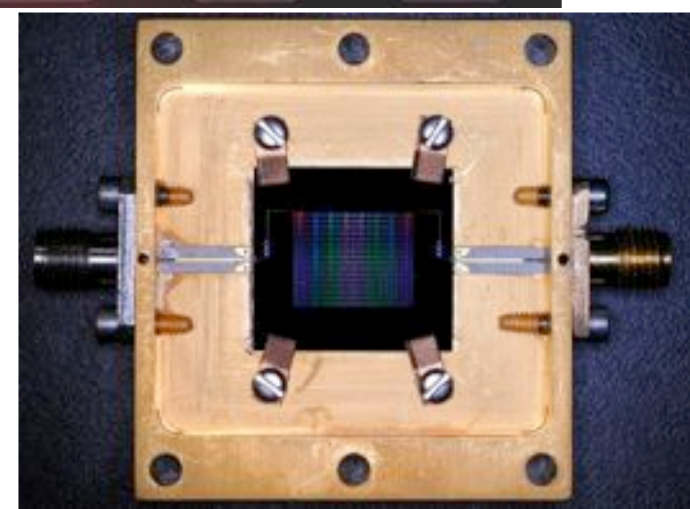
Frequency-multiplexed superconducting microresonator detectors (MKIDs)





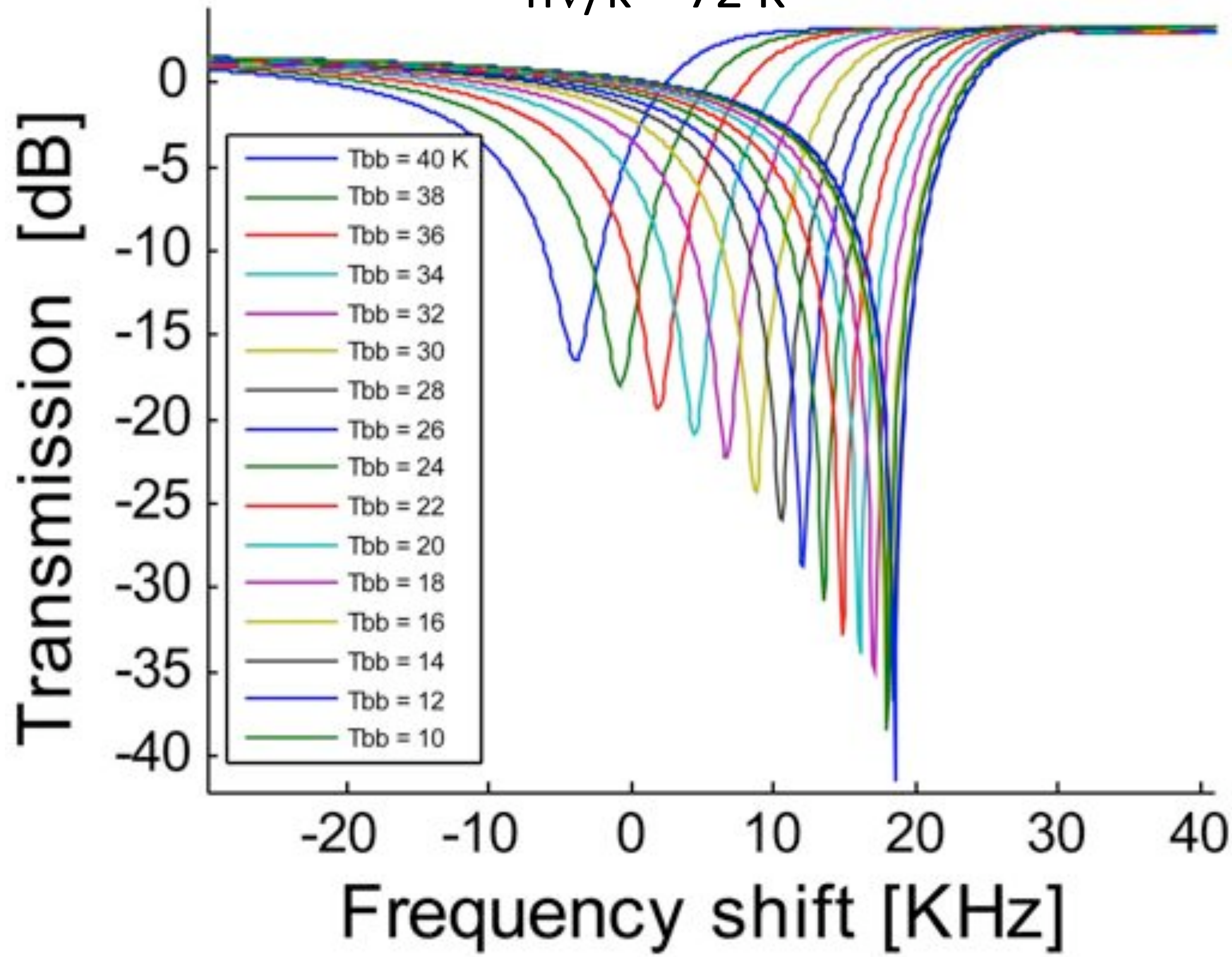






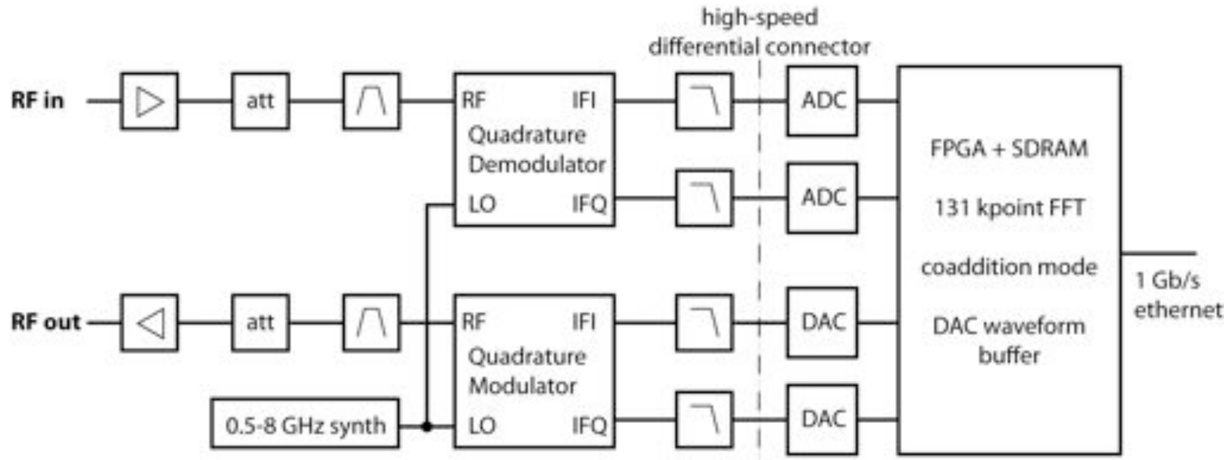
Response to 200 μm blackbody

$h\nu/k = 72$ K



Readout electronics are available now

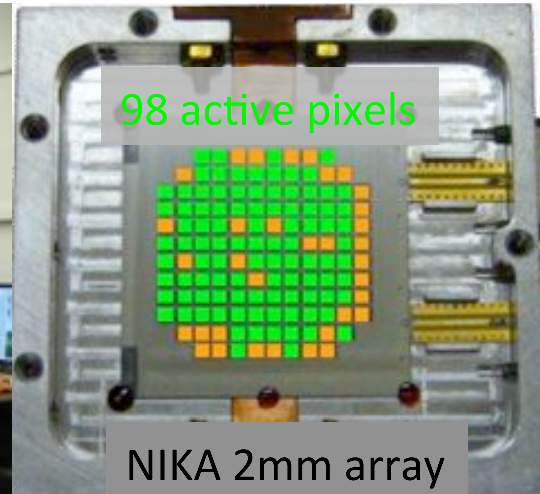
- CASPER/UCB ROACH hardware
- Custom ADC/ DAC/IF boards
- 500 MHz bandwidth
- > 10^6 spectral channels using 2-stage FFT
- Used in MUSIC and NIKA



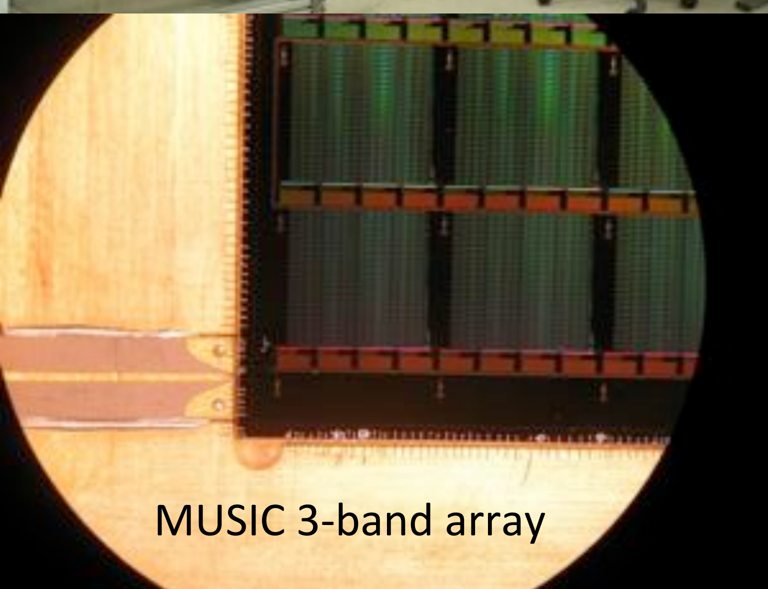
MUSIC & NIKA

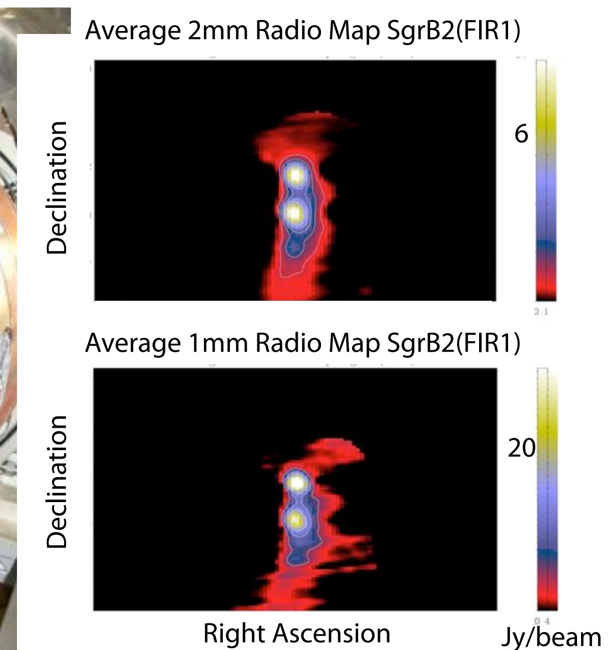
(Maloney et al 2010, Proc SPIE 7741; Monfardini et al 2011, arXiv:1102.0870v2)

"… the 150 GHz LEKID array sensitivity is now comparable to the existing IRAM instrument MAMBO2 at Pico Veleta."



NIKA @ 30m





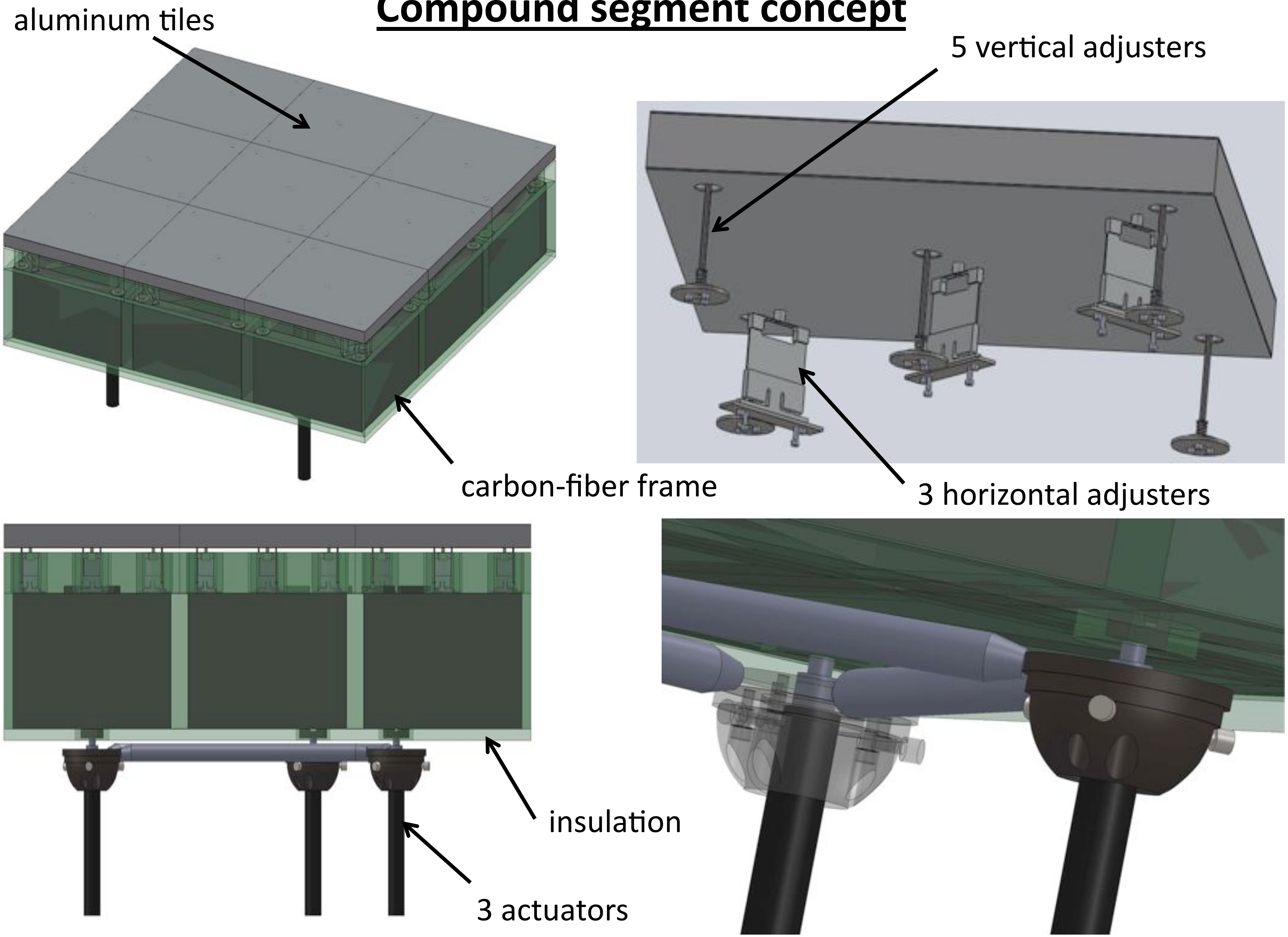
Primary surface

Use rings of keystone-shaped segments, so we have the option of replicating segments.

For simple 3-point support, segment size is limited to ~2m, so 6 rings, for a total of 162 segments.

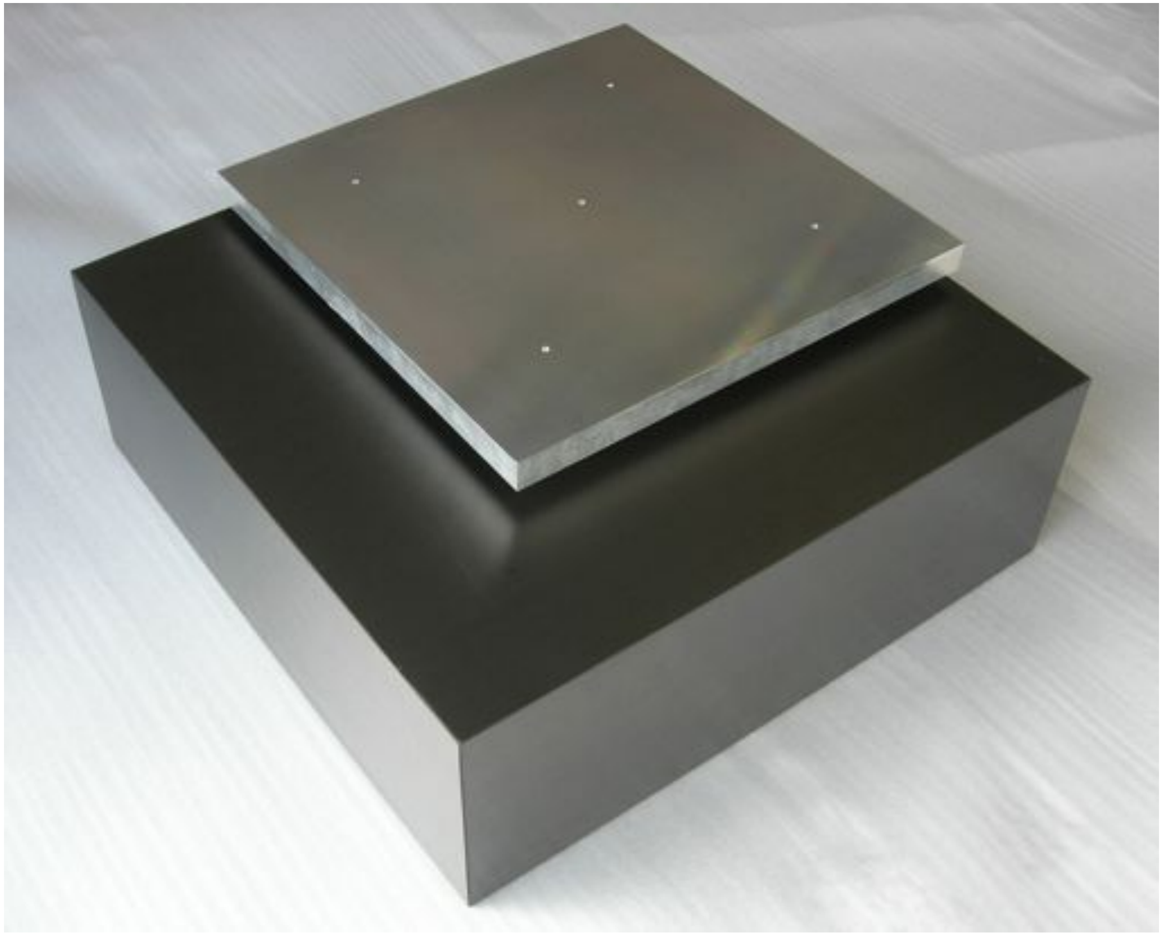
Credit: S. Padin

Compound segment concept



Credit: S. Padin

Prototype tile & subframe

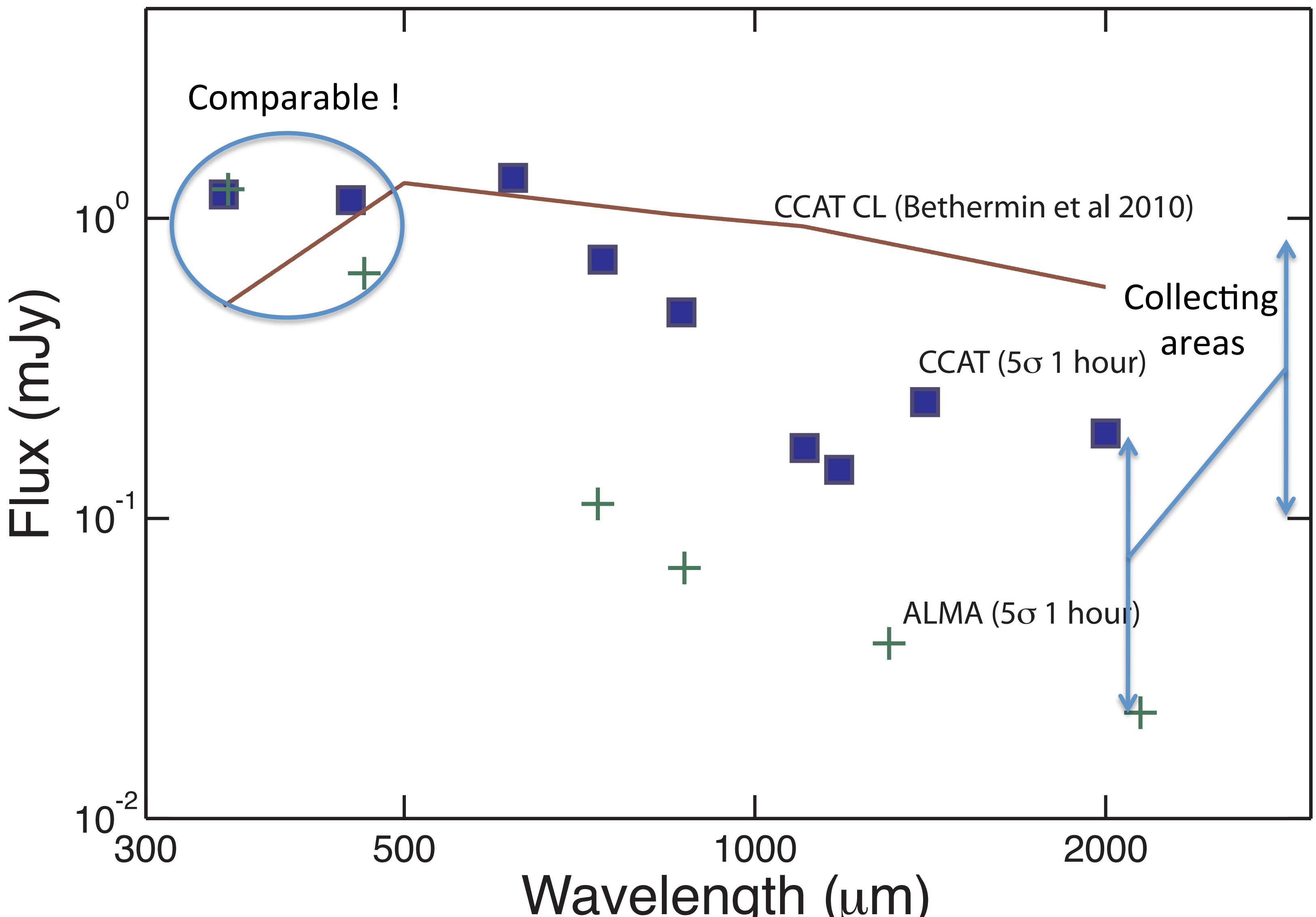


Tile surface error 2.5 μm rms
Tile + subframe areal density 19 kg m^{-2}

Vertex Antennentechnik

Credit: S. Padin

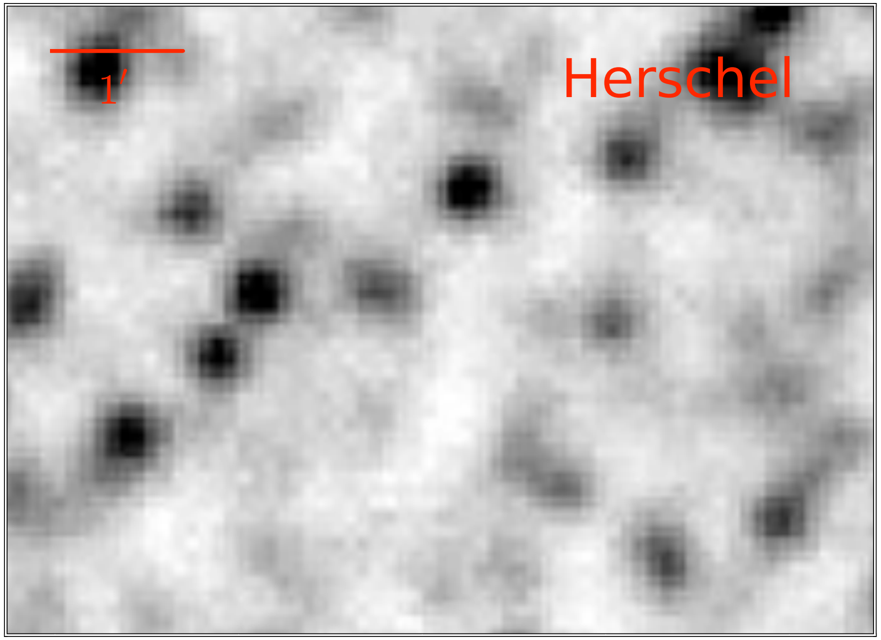
CCAT vs ALMA

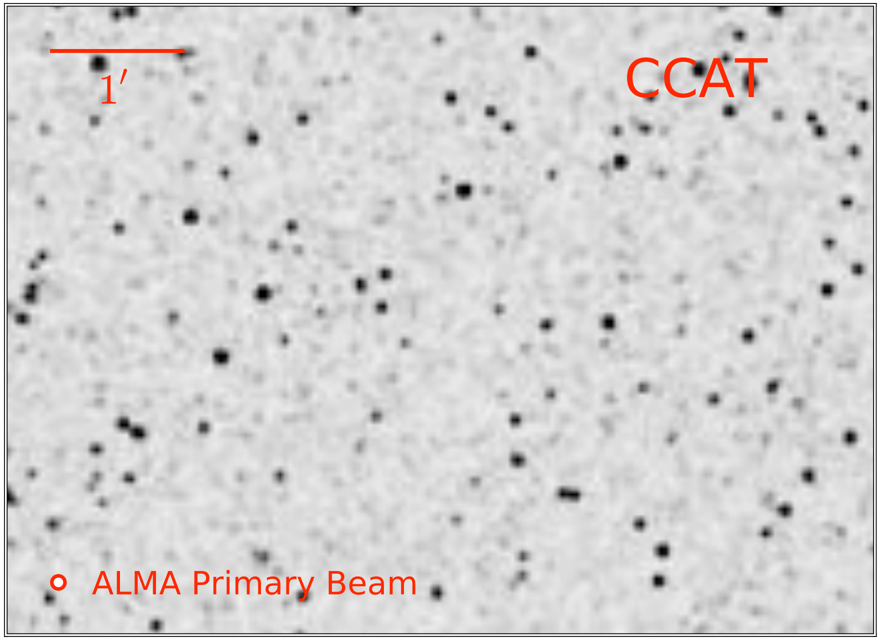


Comparable !
CCAT CL (Bethermin et al 2010)
Collecting areas
CCAT (5σ 1 hour)
ALMA (5σ 1 hour)
Flux (mJy)
10^0
10^-1
10^-2
300
500
1000
2000
Wavelength (μm)

CCAT vs Herschel

350 μm

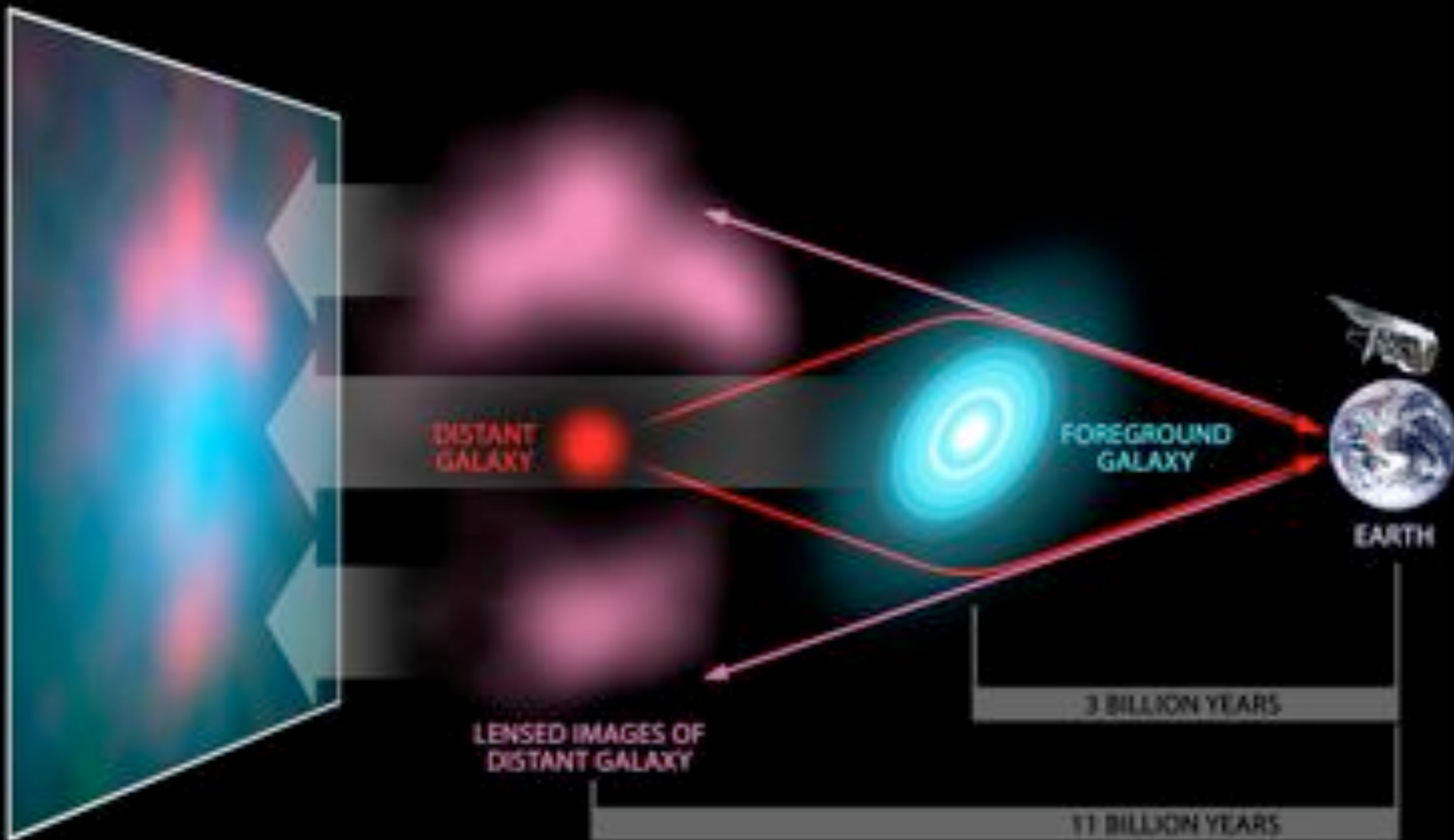




Credit: J. Glenn/U. Colorado

Cerro Chajnantor 5612 m

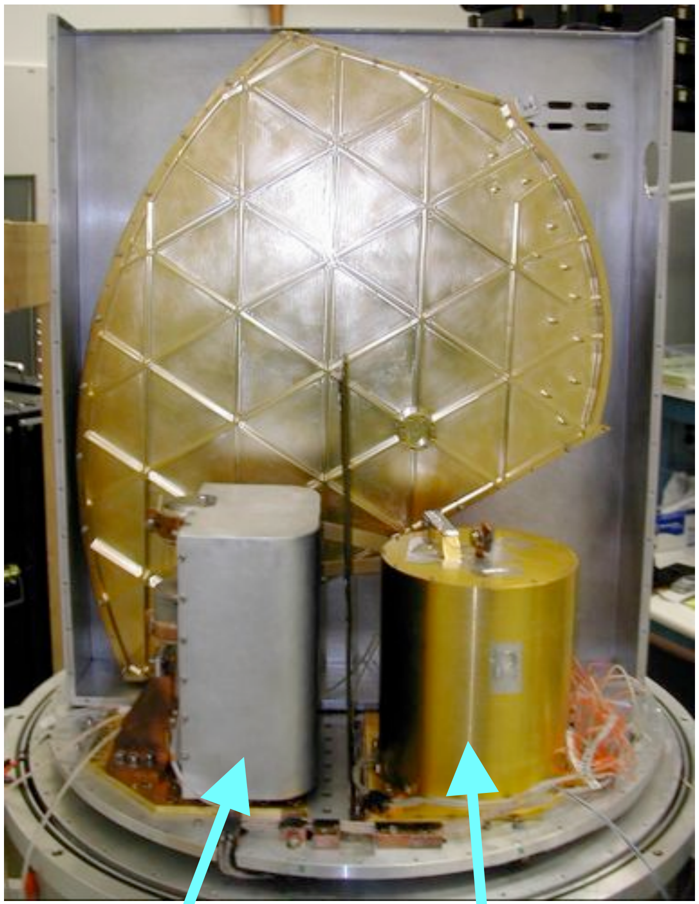
Cerro Chajnantor 5612 m



Negrello et al., Science 330, 800, Nov 5 2010

Z-Spec: wideband mm-wave direct detection spectroscopy

WaFIRS Grating:
62 × 48 × 3.3 cm



^{3}He/^{4}He Fridge

60 mK ADR
(Salt pill courtesy Peter Timbie's group)

Parameters

- λ = 1.0 to 1.5 mm (CSO)
- 160 bolometers
- Δν ~ 900 MHz, Δv ~ 1,000 km s^{-1}

Background

- In 1998, the need for wideband mm/submm spectroscopy was clear following Scuba detections
- 1 mm window best choice for CSO
- Options: optical grating spectrometer, superconducting spectrometer chip
- Machined parallel-plate waveguide grating was the middle ground: Z-spec
- Superconducting spectrometer chip now appears very attractive – Golwala talk

Caltech—*Bret Naylor*, Jonas Zmuidzinas
Cardiff—Peter Ade
CEA (France)—Lionel Duband
Colorado—*James Aguirre, Lieko Earle*, *Jason Glenn*, Phil Maloney, Corey Wood
JPL—Jamie Bock, *Matt Bradford*, Hien Nguyen
ISAS (Japan)—Hideo Matsuhara

Credit: M. Bradford

Summary

- CCAT is designed for submm surveys
  - Wide field of view
  - High sensitivity (25 m, excellent site)
  - Good angular resolution (3".5 at 350 μm)
  - Broad wavelength coverage
- Leading-edge instruments
  - Wide-field cameras
  - Multi-object or integral-field spectrometers
- Aiming for completion by 2018
- See www.submm.org