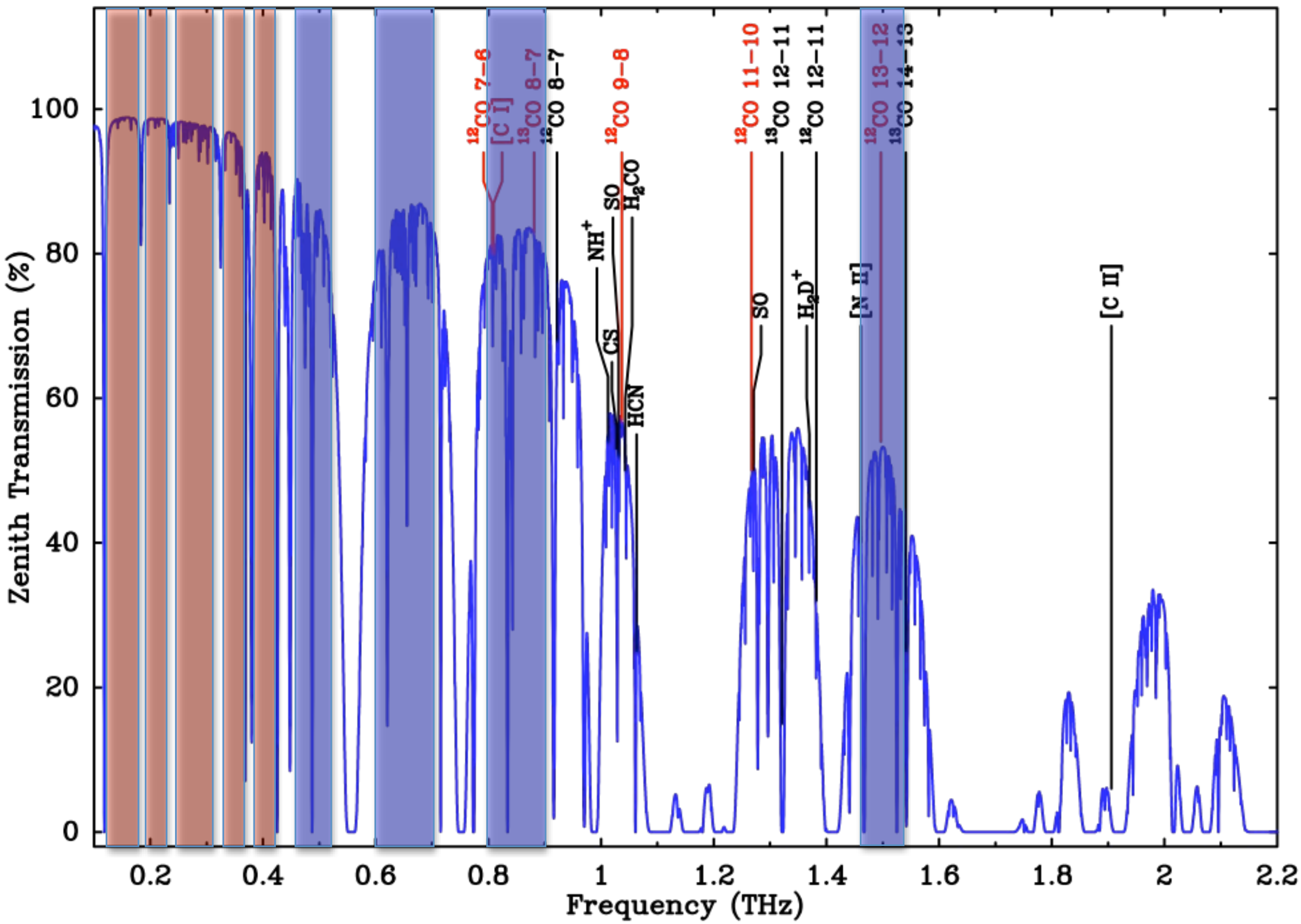
Instrumentation and Detectors

Jonas Zmuidzinas

Caltech

Measured transmission at Sairecabur

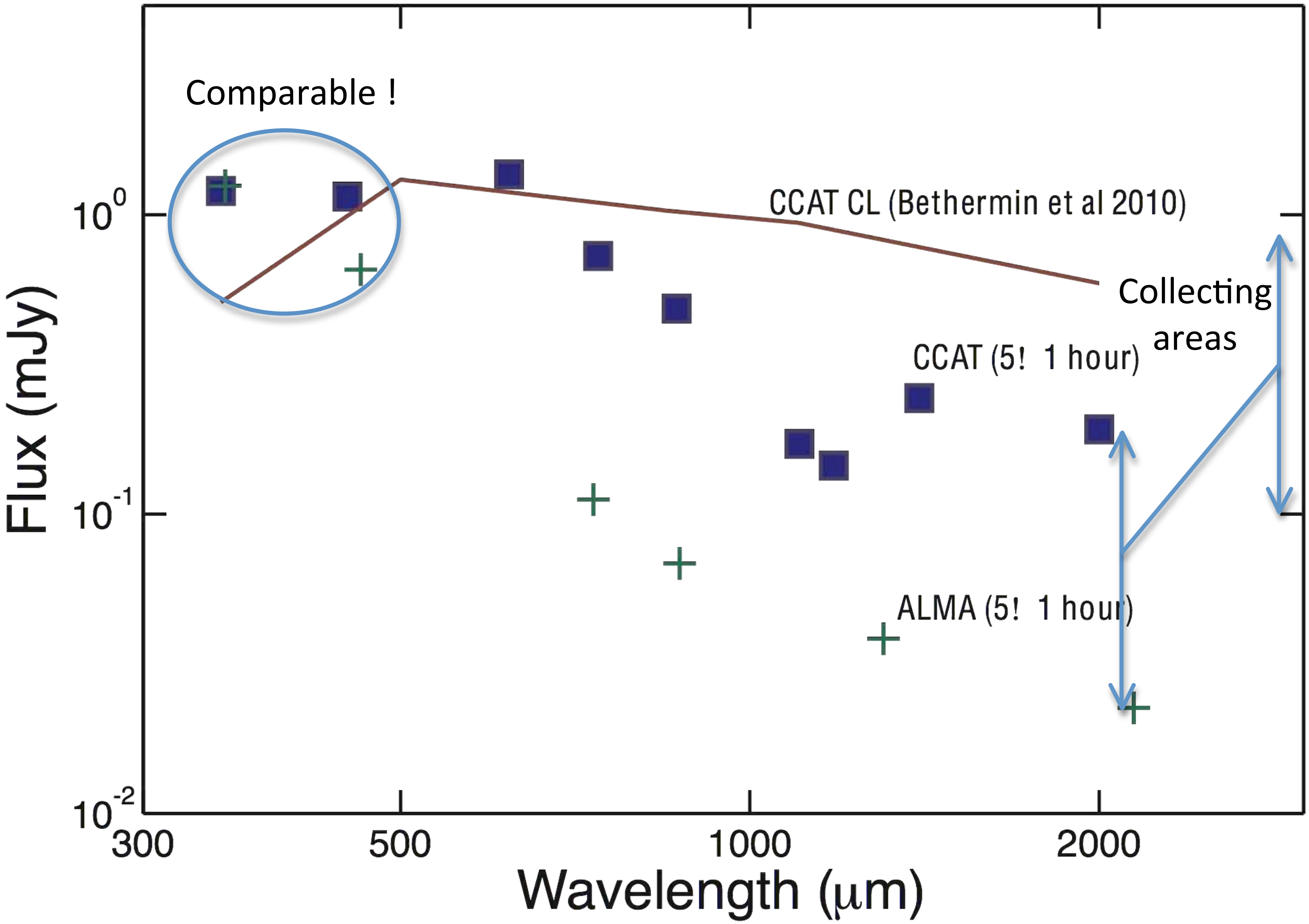
Marrone et al 2005; 93 μm PWV



LWCam
2.0 mm
1.4 mm
1.1 mm
850 μm
740 μm

SWCam
620 μm
450 μm
350 μm
200 μm

CCAT vs ALMA



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

CCAT Strengths

- Outstanding site
  - Better transmission, lower atmospheric emission at short submm wavelengths
- Direct detection
  - Operate near photon noise limit (avoid Rx noise)
  - Wide bandwidth gives x3 sensitivity boost
- Single dish with wide field of view
  - Arrays boost mapping speed by N/4 to N/16
  - Multiobject spectrometers
- *Leads to emphasis on short submm, wide bandwidth, array instruments*

2006 Feasibility Study

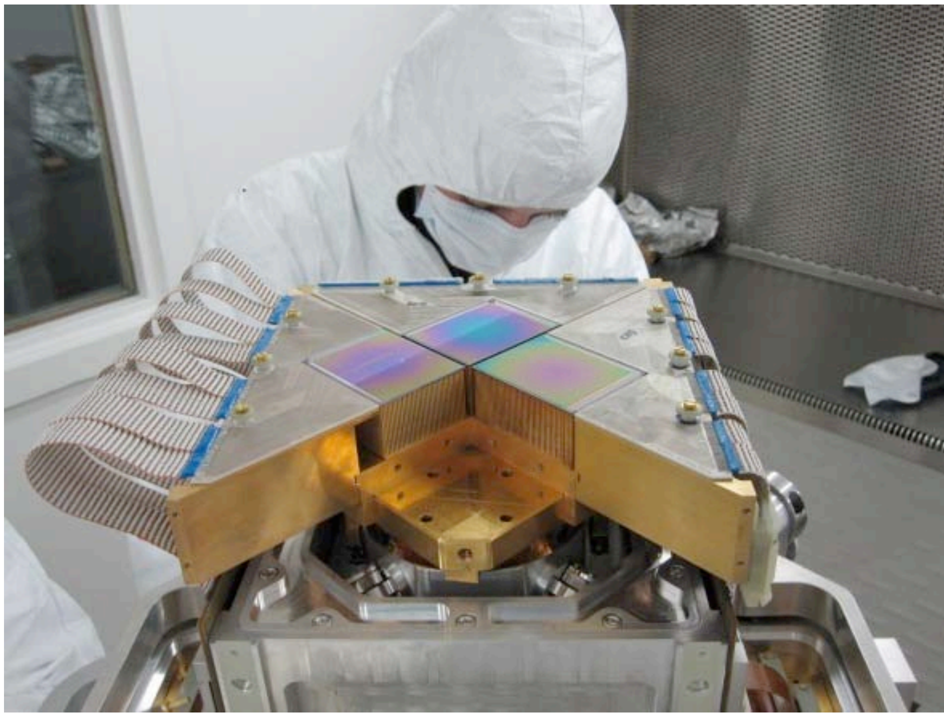
Table 6.1a. 8890,W*%$,Y*51$,!"#$%&' ("$#					
,	**Band Center**	**Resolving Power**	**Number of pixels**	**Arcseconds/pixel**	**Field of View**
SWCam Stacey 3:00 pm	DTT, !' , HUT, !' , KUT, !' , -DT, !' ,	DH, [, [, Z,	HDGTT,	/ NZU#,	UNTU, V, UNTU,
LWCam	ZKT, !' ,	/ HNU,	/ - H[K,	KNZ#,	/ T!, V, / T!,
	,	,	HTZD,	/ \ #,	DT!, V, DT!,
Golwala	[ZT, !' ,	[N[,	/ - H[K,	KNZ#,	/ T!, V, / T!,
11:40 am	,	,	HTZD,	/ \ #,	DT!, V, DT!,
Saturday	/ N, ' ' ,	UNU,	KT\ - ,	/ \ #,	DT!, V, DT!,
	/ NK, ' ' ,	UNU,	/ TDK,	HZ#,	DT!,, V, DT!,
	DNT, ' ' ,	U,	/ TDK,	HZ#,	DT!,, V, DT!,
	0+$)6,] ($(4$+%,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,KUGU- ,				

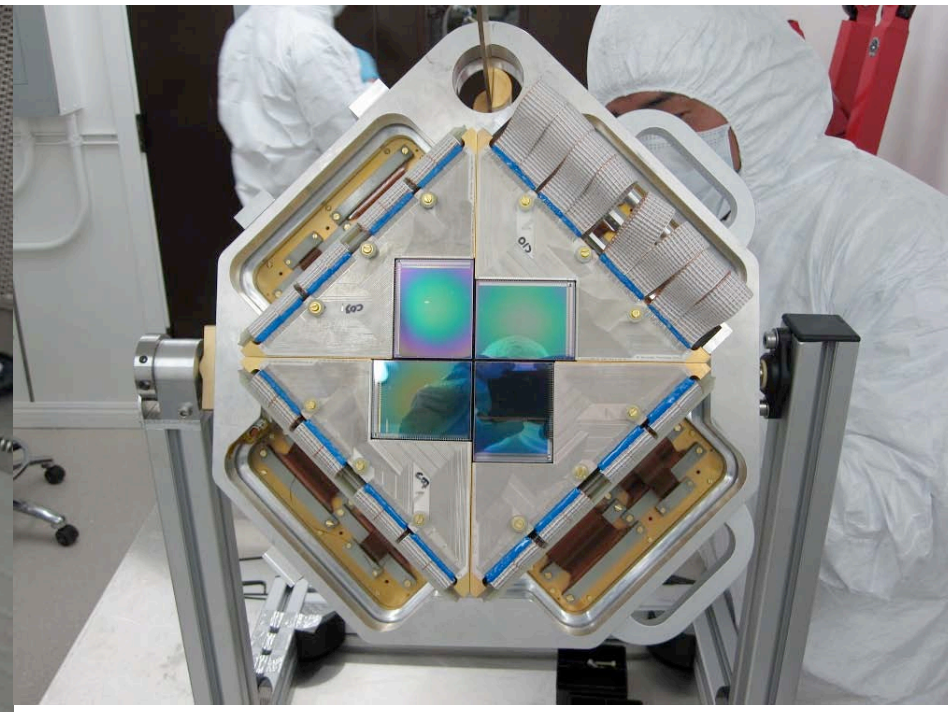
Multicolor = observed simultaneously!

Background limited sensitivity

Instrument budget: $20M

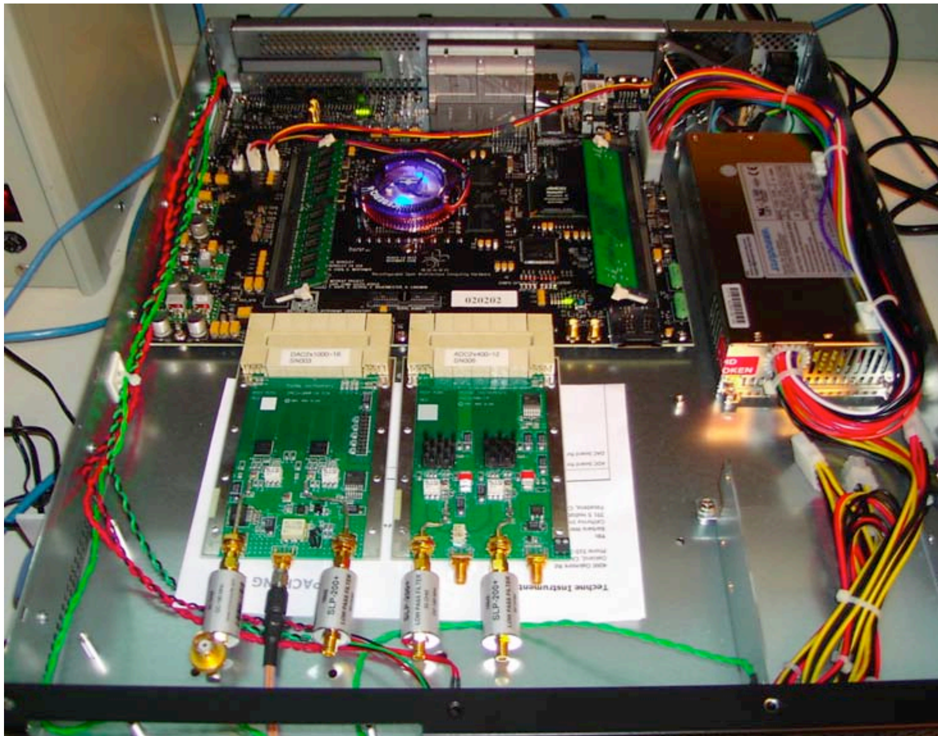
SCUBA 2: 10k pixels

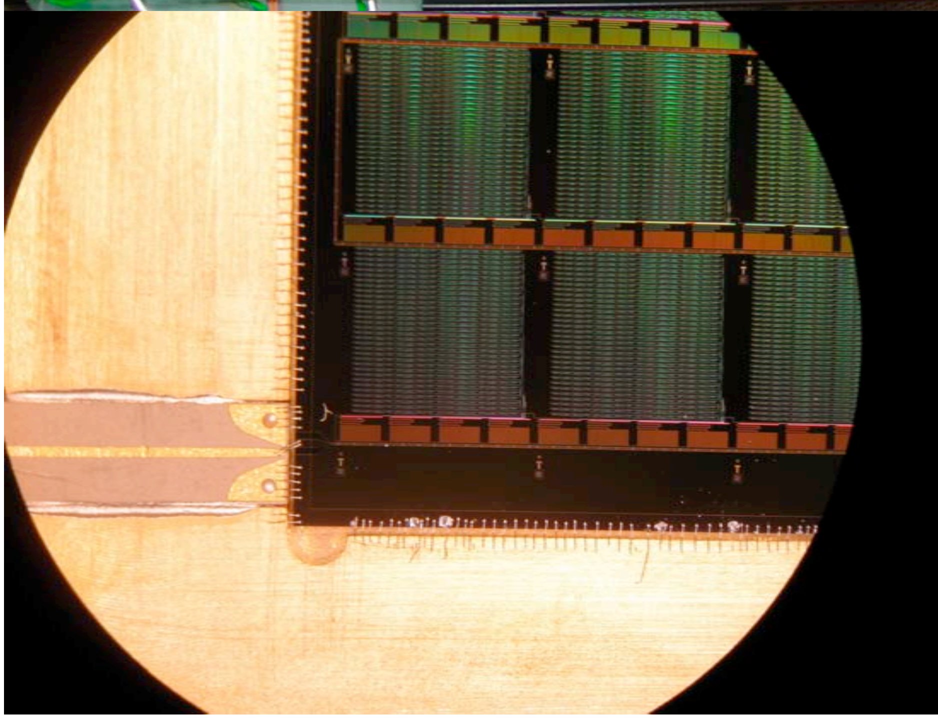




Mike Fich, 2:40 pm

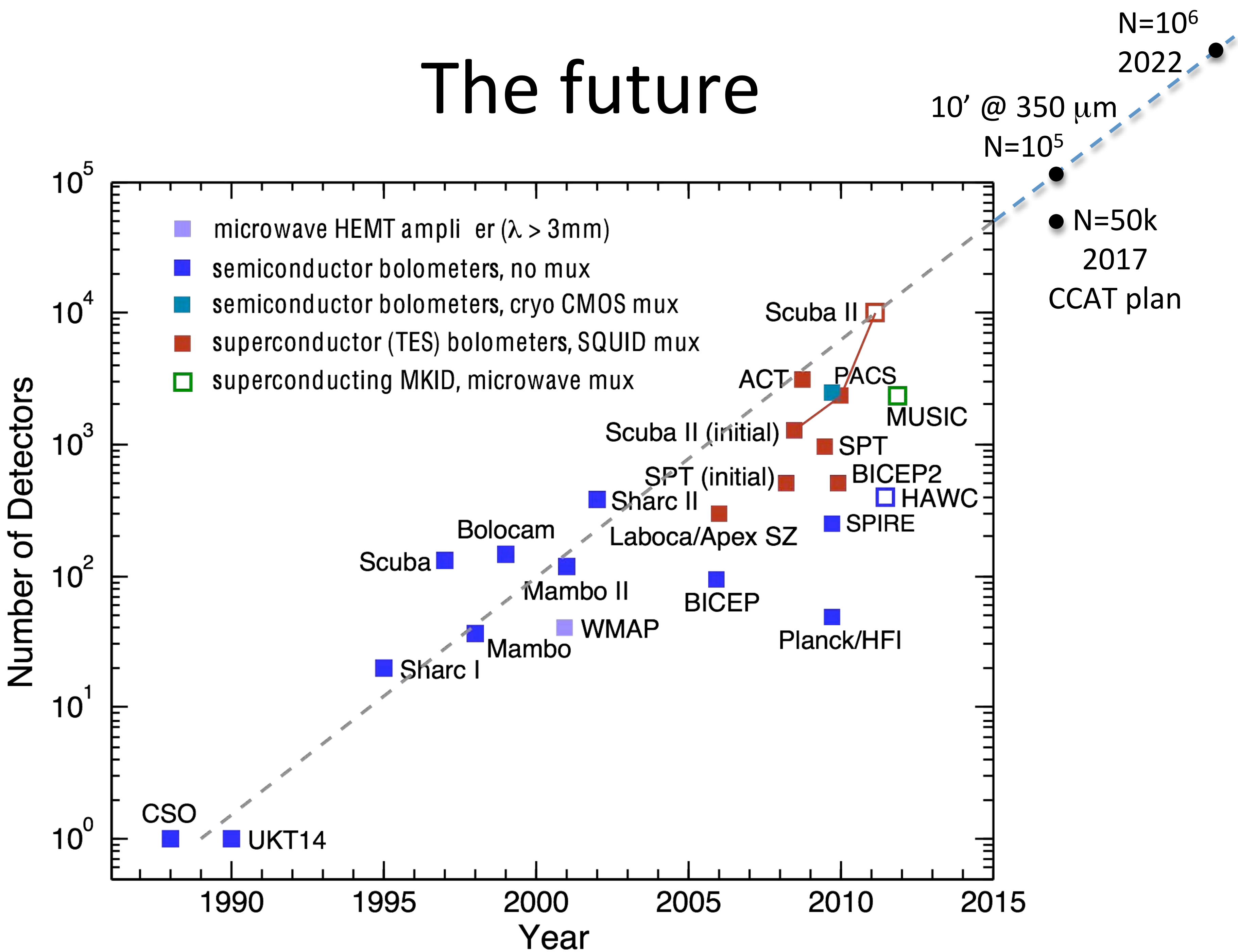
MUSIC





- 24x24 array, x4 bands
  - 2304 detectors
- Antenna-coupled MKIDs
- CSO deployment in 2011
- Golwala - Saturday

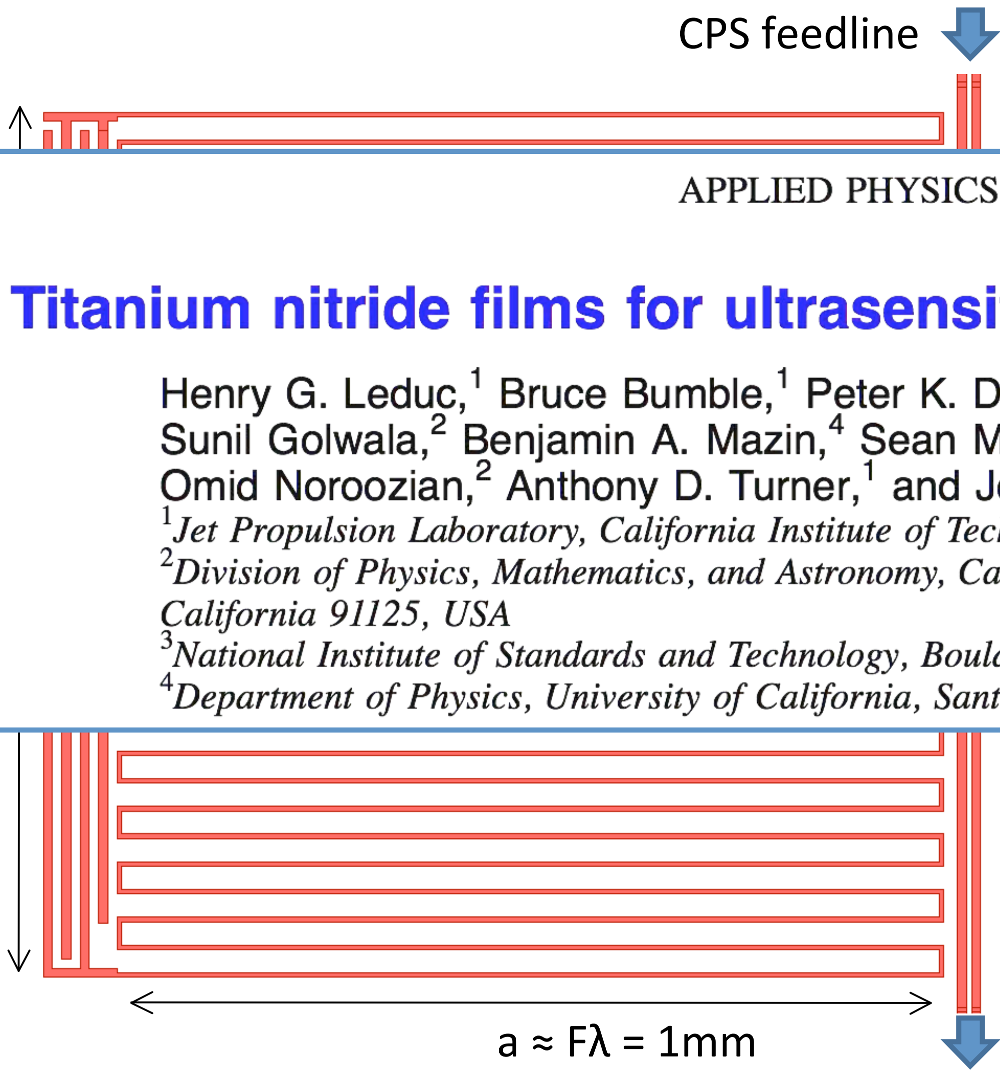
The future



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

Titanium Nitride Direct-Absorption MKIDs

- Cardiff style lumped element resonator



APPLIED PHYSICS LETTERS **97**, 102509 2010

Titanium nitride films for ultrasensitive microresonator detectors

Henry G. Leduc,[1] Bruce Bumble,[1] Peter K. Day,[1] Byeong Ho Eom,[2] Jiansong Gao,[3] Sunil Golwala,[2] Benjamin A. Mazin,[4] Sean McHugh,[4] Andrew Merrill,[4] David C. Moore,[2] Omid Noroozian,[2] Anthony D. Turner,[1] and Jonas Zmuidzinas[2,a]
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[3]*National Institute of Standards and Technology, Boulder, Colorado 80305, USA*
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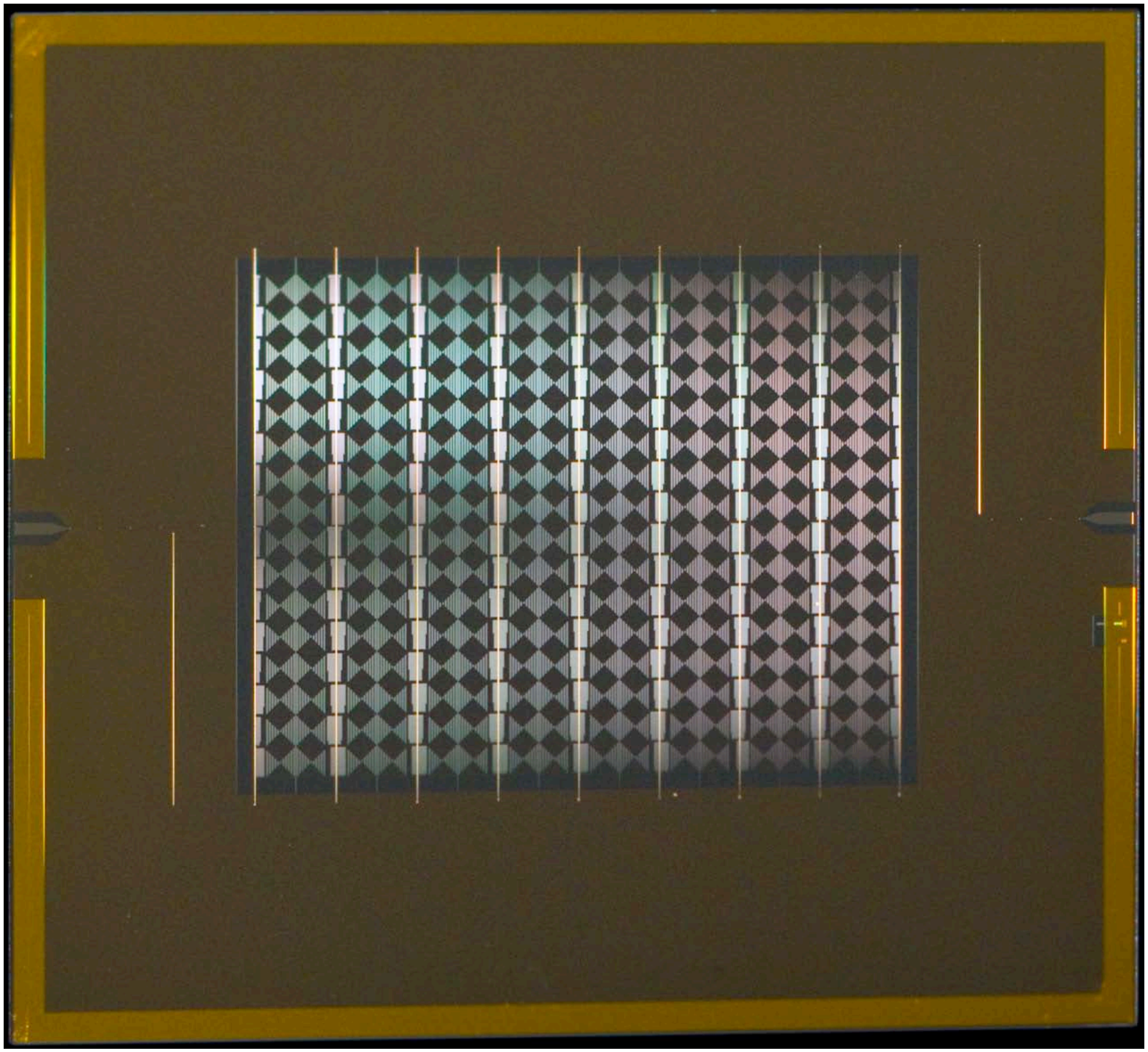
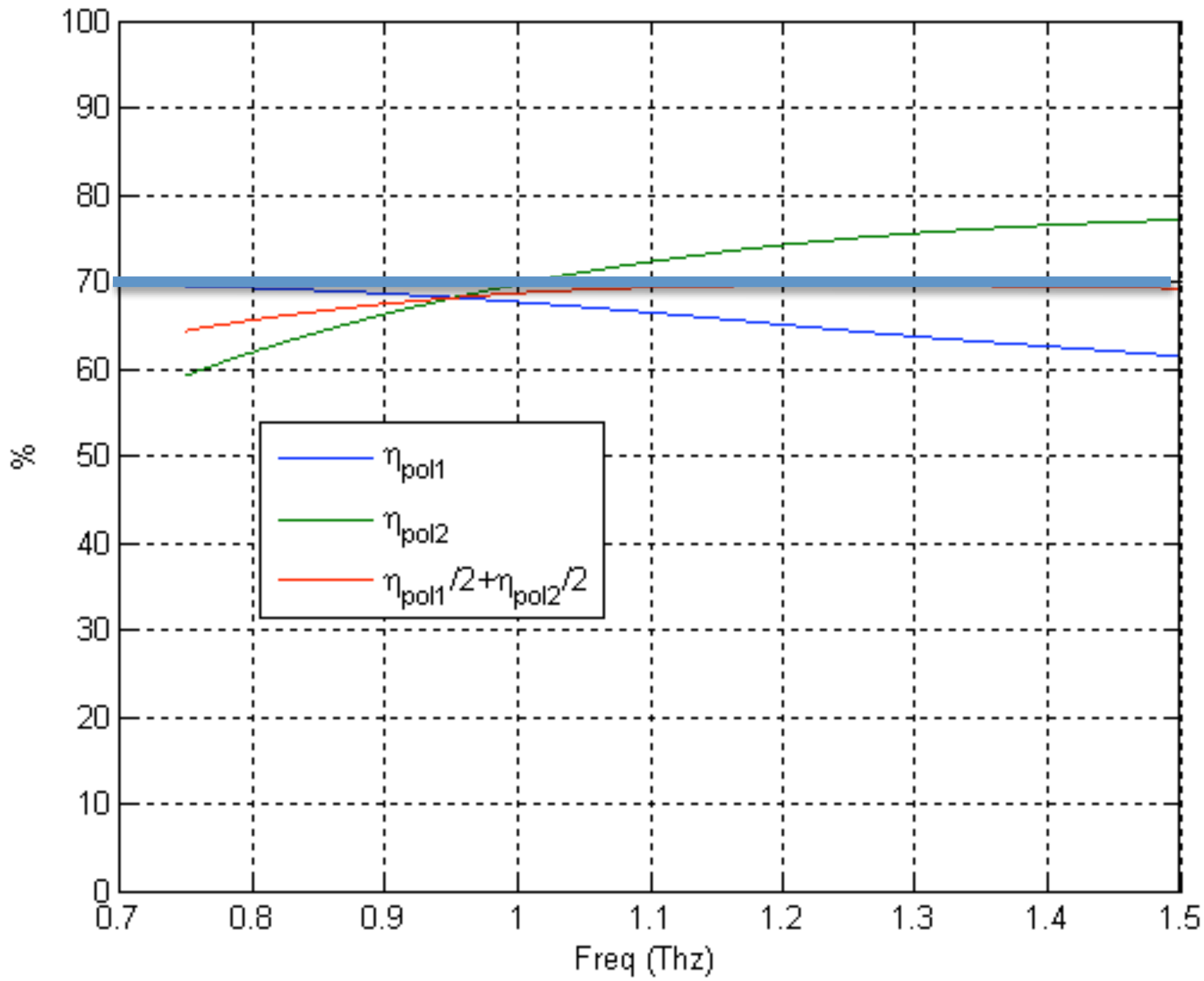
TiN MKID Array (16x16)



Dual-polarization absorber-coupled MKID:

Calculated absorption properties for R_s = 20 Ω/square

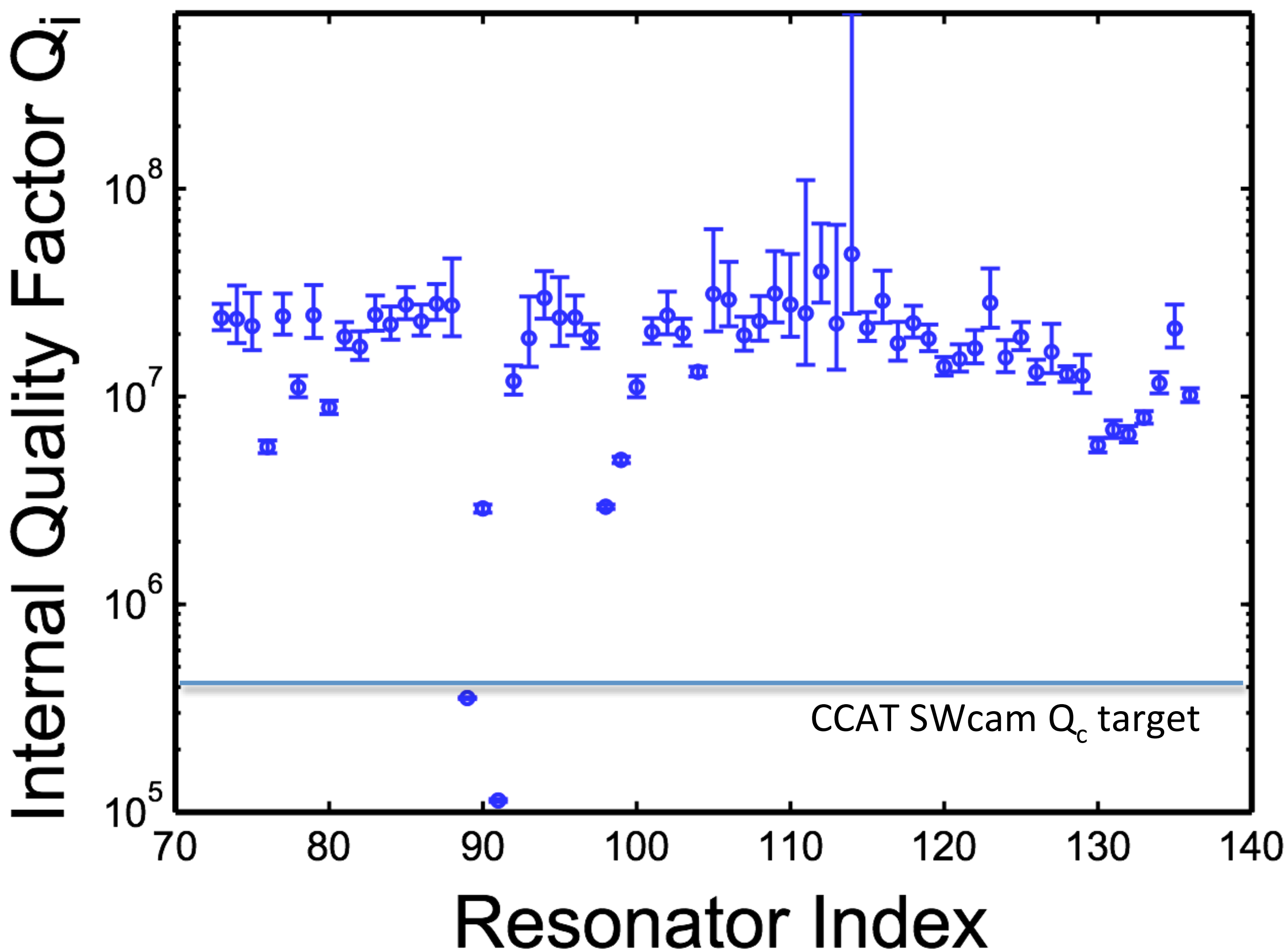


Optimum sheet absorber on silicon substrate

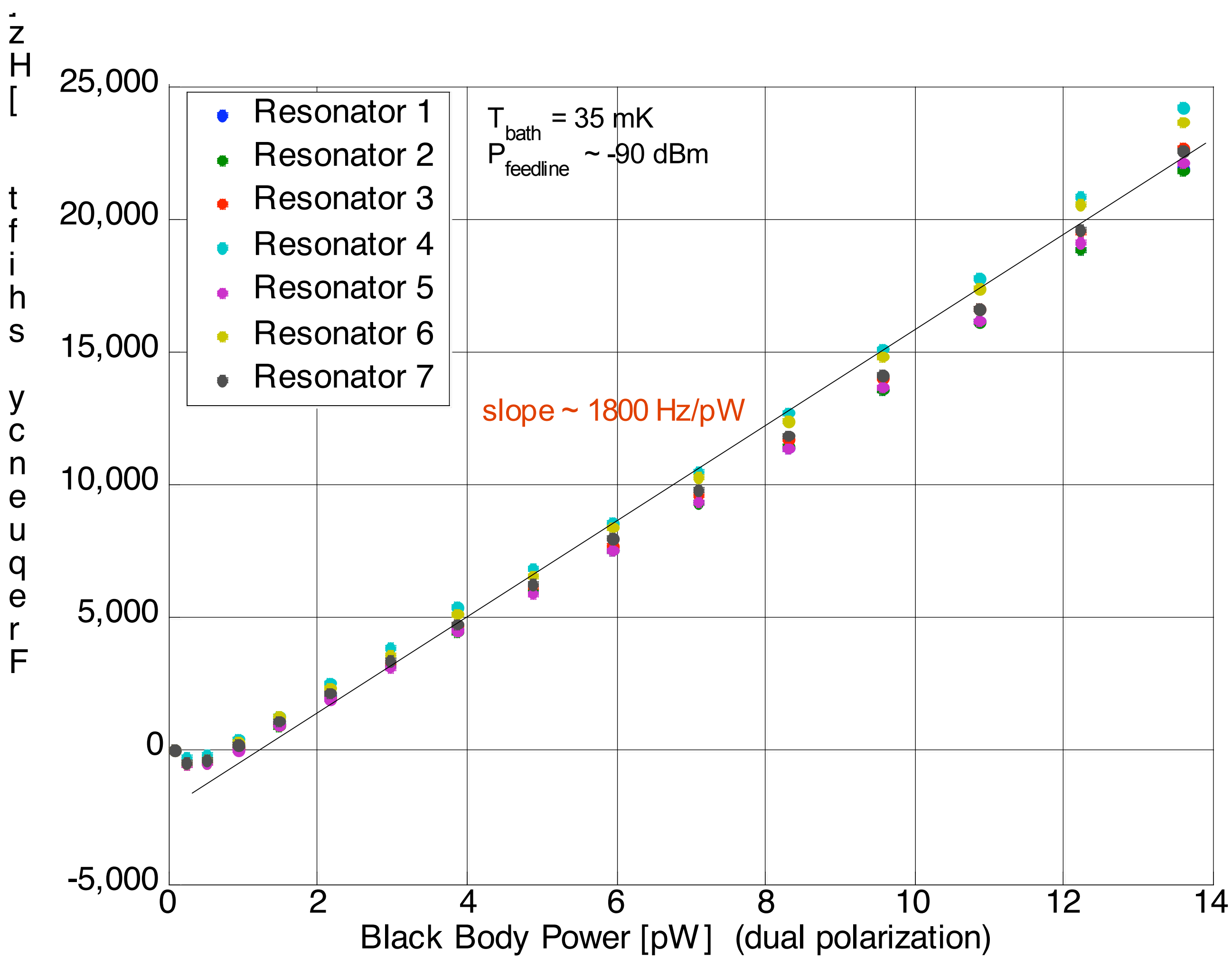
N. Llombart, 18-09-2010

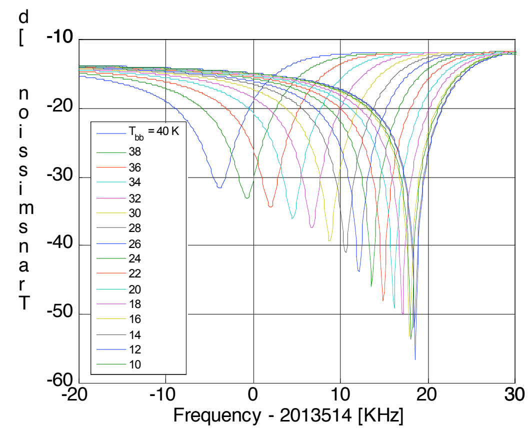
Record high Q with TiN

(with high pixel yield)



Response to 200 μm blackbody





TiN MKID summary

- Extremely simple design and fabrication
- Array design developed and demonstrated
  - Very low interpixel crosstalk
  - High pixel yield, Q, mux density
- NEP, optical load adjustable over wide range since T_c varies with stoichiometry
- Costs will be dominated by readout electronics, not detectors
  - Uses standard commercial silicon integrated circuits
  - Currently around $10 per pixel
- MKID noise understood
  - Actually from capacitor, not MKID !
  - Avoid by using dissipation readout
- Opens path to very large instruments, ultimately filling 1 degree FOV

Astro2010 RFI2

(July 2009)

- At first light, the goal is to have cameras with up to about 50 Kpix available: one at short wavelengths, 200 to 620 μm, and one at long wavelengths, covering 740 to 2000 μm.

- Following the deployment of the cameras by no more than 2 years, a broadband direct-detection grating spectrometer is required, capable of observing 10 – 100 objects simultaneously while spanning multiple atmospheric windows in order to determine *z* via the [CII] or CO lines

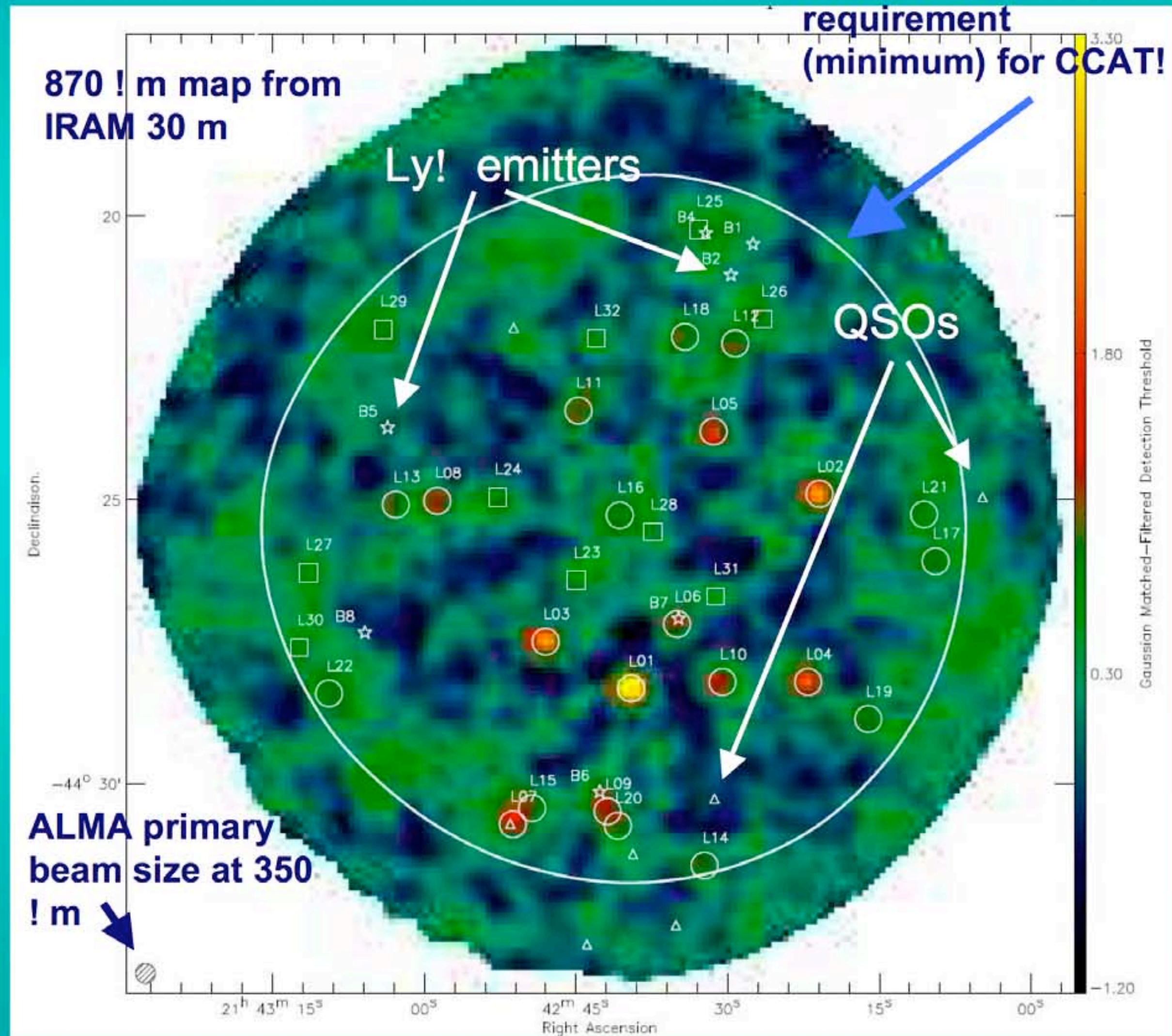
Why Do We Need *Multi-Object* Spectroscopic Capability?

Speed of follow-up & galaxy clustering

Submillimeter galaxies in the vicinity of z = 2.38 Ly! clouds J2143-4423
(Galaxy "protocluster"?)
Circles: probable detections (22)
Squares: possible detections (10)

Photometric redshifts indicate seven or more 5 – 20 x 10^{12} L_{solar} galaxies with 2.0 < z < 2.8
spectroscopic redshifts are needed.

Approximate F.O.V. requirement (minimum) for CCAT!



J. Glenn, 2008

Beelen et al., astro-ph/0803.1615

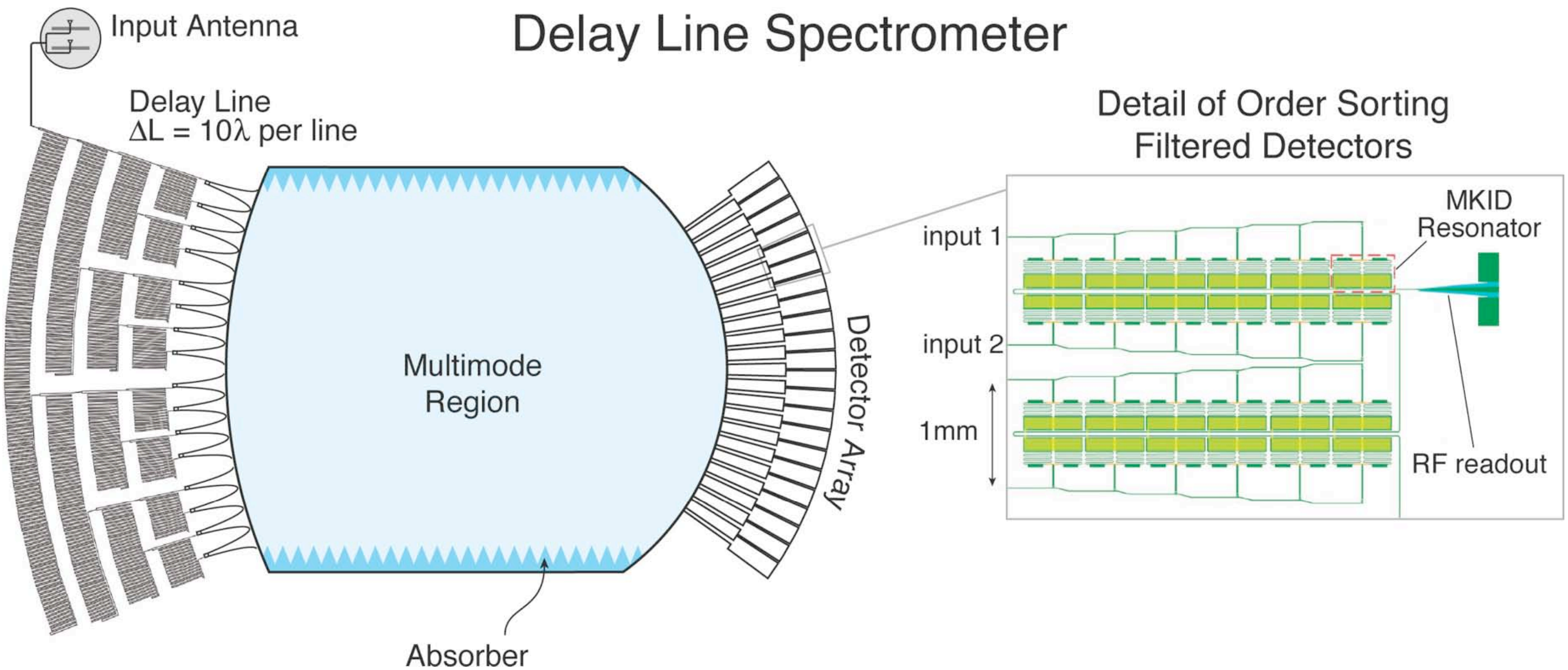
Spectrometer Options

- Classical free-space grating spectrometer
  - ZEUS2: Nikola, Saturday 1:20 pm
- Parallel-plate waveguide grating
  - Matt Bradford, Saturday 1:40 pm
  - James Aguirre, Saturday 2:20 pm
  - CO redshifts of targets found by Herschel/SPIRE (Negrello et al, Science, Nov 5 2010)
- Need method to select objects in field
  - Submm fibers (Glenn et al)
  - Mirror schemes (Seiffert & Goldsmith; Bally)
- Fabry-Perot ?? (BIFI)
- Spectrometer size will be key issue
- Detectors will not be a limitation

Compact Integrated Spectrometers

Moseley – μSPEC

2:40 pm Saturday



The μ-Spec design uses delay lines to create the phase delay for R~1500 spectroscopy, and can be fabricated on a single 10 cm wafer. It can produce diffraction-limited line images across the focal surface. The synthetic grating operates in high order (~10), and compact filter banks (right) separate the orders and direct them to individual MKID detectors.

High-Resolution Spectroscopy with CCAT

- Stutzki 2008:
  - science calls for a multi-color heterodyne array receiver
  - Modular/interchangeable detector arrays to cover 600, 450, 350, and 200 mm
  - Flexible IF processing/DFT spectrometers
    - 4 GHz per pixel in array
    - Or very wide bandwidth for line surveys
- A kilopixel heterodyne array for CCAT ?
  - Walker, 10 am Saturday
- NEW! Ultra-wideband rapid line survey instrument ?
  - Cover 350 μm and 450 μm windows simultaneously
  - 200 GHz bandwidth with ultra low noise

Summary

- Technology for cameras progressing well
  – Solutions for full degree FOV are on the horizon
- Multi-object spectrometer concepts and technology need attention
  – MOS should be completed within ~2 yrs of cameras
  – Will need to select technology in several years
- Plan for heterodyne instruments should be developed