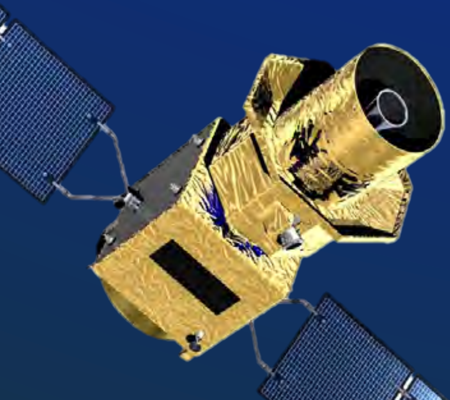
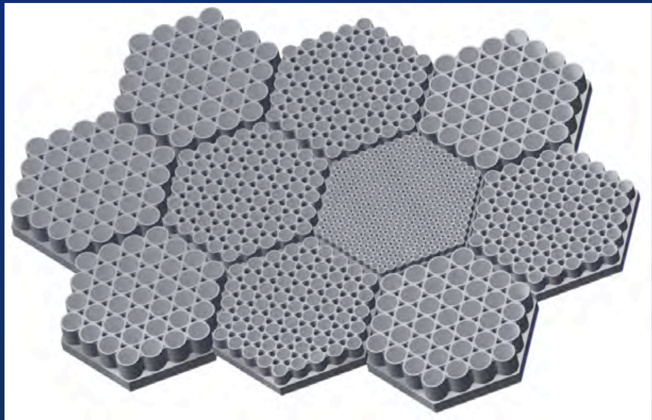
MKID Focal Plane Array for LiteBIRD

Yutaro Sekimoto

National Astronomical Observatory of Japan

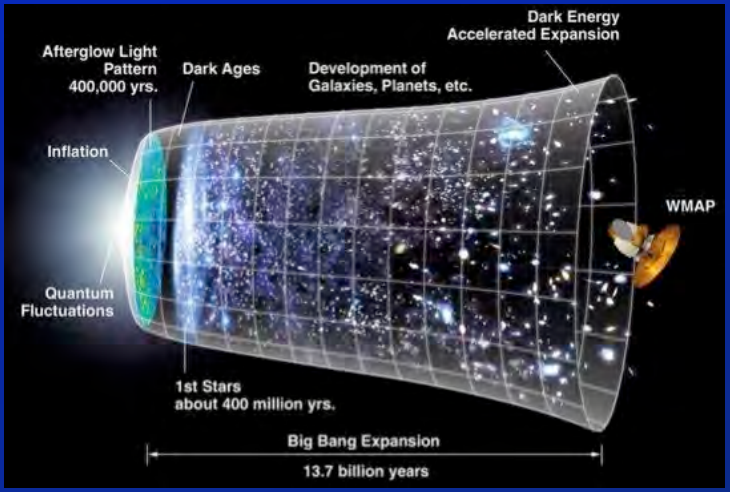




共同研究者

- National Astronomical Observatory of Japan
  - W. L. Shan, A. Dominjon, T. Noguchi, H. Kiuchi, M. Sugimoto, H. Matsuo, N. Okada, M. Fukushima, Y. Obuchi, K. Mitsui
- Department of Astronomy, University of Tokyo
  - M. Sekine, S. Sekiguchi, S. Shu
- Institute of Physics, University of Tsukuba
  - T. Nitta, N. Nakai, N. Kuno, M. Nagai, H. Imada, Y. Yamada, S. Hisamatsu
- Graduate School of Science and Technology, Saitama University
  - M. Naruse, H. Myoren, T. Taino
- Institute of Space and Aeronautical Science (ISAS), JAXA
  - A. Miyachi, M. Mita, S. Kawasaki, T. Matsumura
- RIKEN
  - C. Otani, S. Mima
- KEK
  - M. Hazumi, O. Tajima, S. Oguri
- Kavli IPMU, University of Tokyo
  - N. Katayama, H. Sugai
- Okayama University
  - H. Ishino, A. Kibayashi

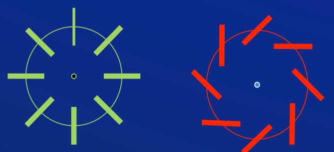
LiteBIRD



Lite (light) satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection

- 50 - 300 GHz
- Launch is planned in early 2020s by JAXA
- T. Matsumura et al. 2015 LTD

E-mode B-mode

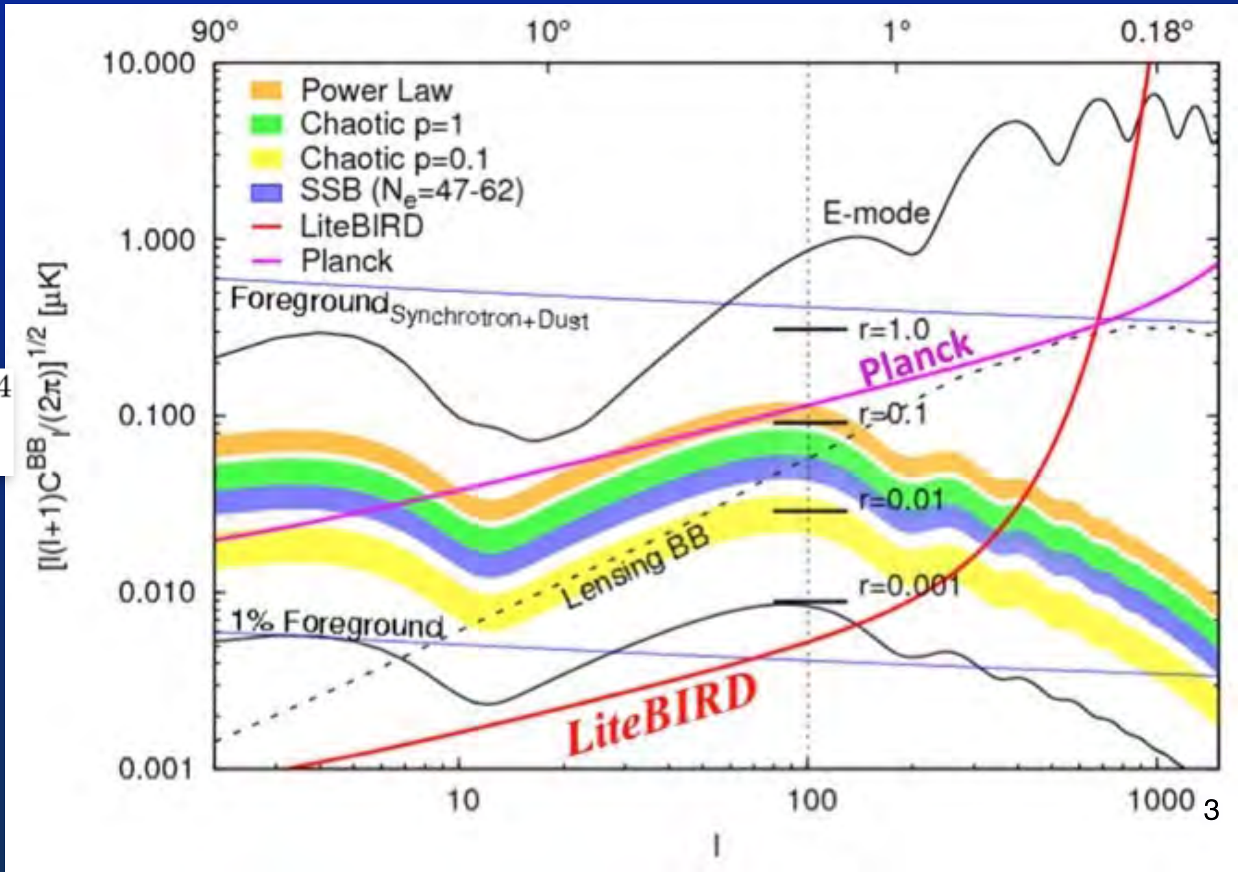


Inflation potential energy

$$V^{1/4} = 1.1 \times 10^{16}\mathrm{GeV}\left(\frac{r}{0.01}\right)^{1/4}$$

r: tensor to scalar ratio

$$r \equiv \frac{\Delta^2_{grav}(k_*)}{\Delta^2_R(k_*)}$$

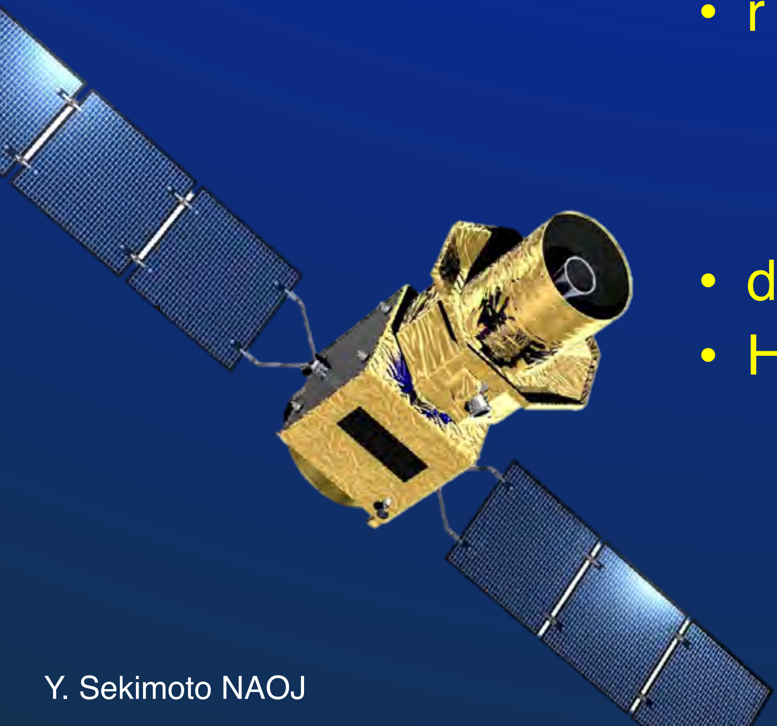


Y. Sekimoto NAOJ

LiteBIRD mission

T. Matsumura et al. 2015 LTD

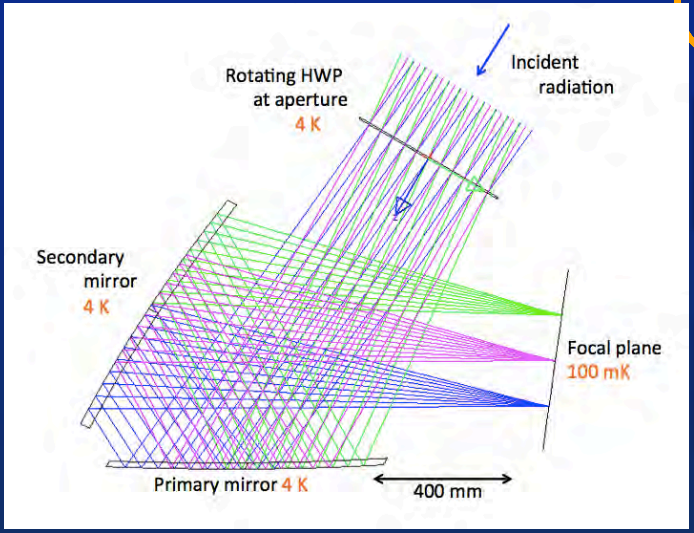
- JAXA mission
  - Mission Definition Review (MDR)
  - Phase A1 review 2016 April
- Launch early 2020s
  - orbit : L2
- r = 0.002 (2 σ)
  - Sensitivity 3 μK arcmin
  - Cryogenic Optics ~ 5 K
  - 100 mK stage with ADR or dilution
- detector : TES or MKID
- Half-wave plate



Focal plane requirements

1. Optical Quality
    1. Each polarization
        1. beam shape (ellipticity, far & near side lobes)
        2. polarization alignment
        3. Cross polarization
    2. Differential Beam
        1. Differential beam pointing (beam squint)
        2. Differential gain (Main & Side lobes)
2. Sensitivity
    1. Noise
    2. Optical efficiency
    3. Dynamic range for calibration
    4. Stability (1/f knee)
3. Environment
    1. Power Consumption (0.1K, 4K, 20K)
    2. Microphonic
    3. Cosmic ray
    4. Weight
    5. Volume

K. Kimura et al.



Optics
(Antenna, HWP,
Baffle, Cold stop, filters)

Feeds

Sensors

Cryogenic Amplifiers

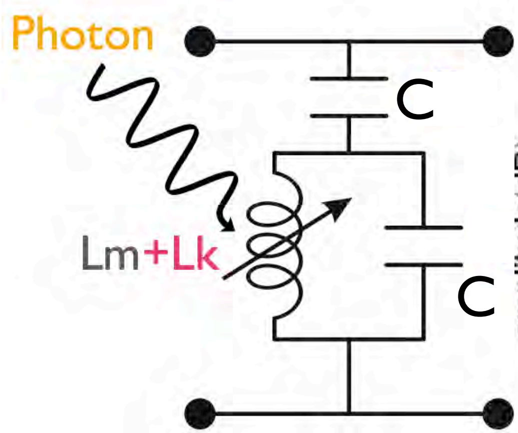
Readout Circuits

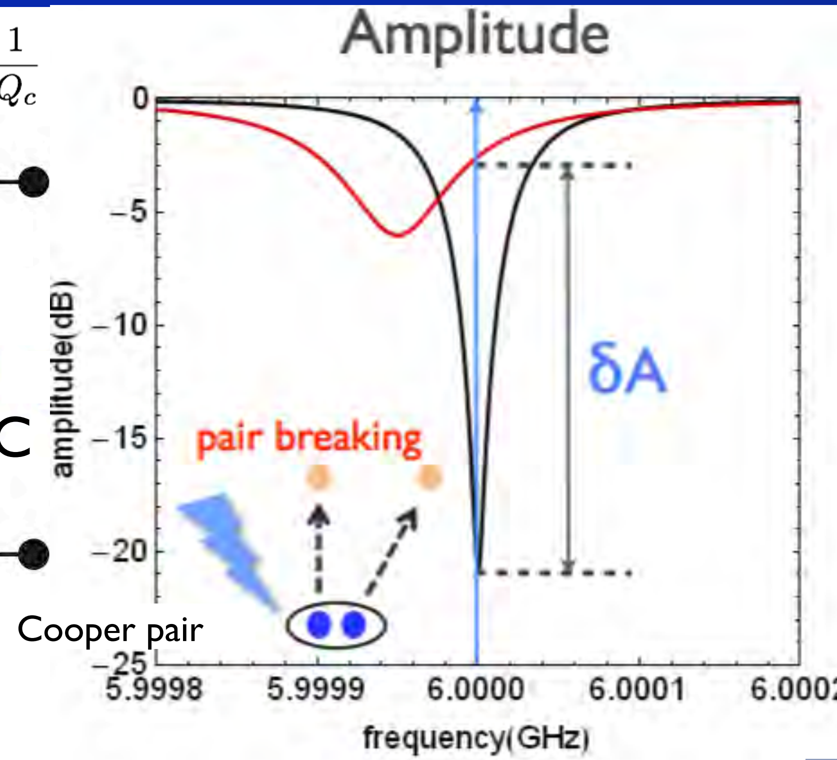
Microwave Kinetic Inductance Detector (MKID)

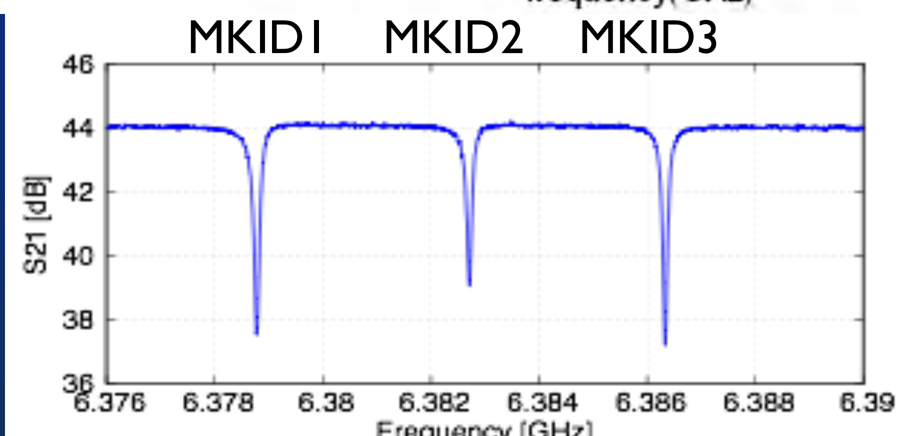
P. Day et al. 2003 Nature
J. Zmuidzinas 2012 ARCMP
J. Baselmans 2012 JLTP

$$\frac{1}{Q_r} = \frac{1}{Q_i} + \frac{1}{Q_c}$$

1. MUX: one pair of coaxial cable for 1000 channels
2. No bias : high yield
3. Large dynamic range
4. Robust over thermal and mechanical variation





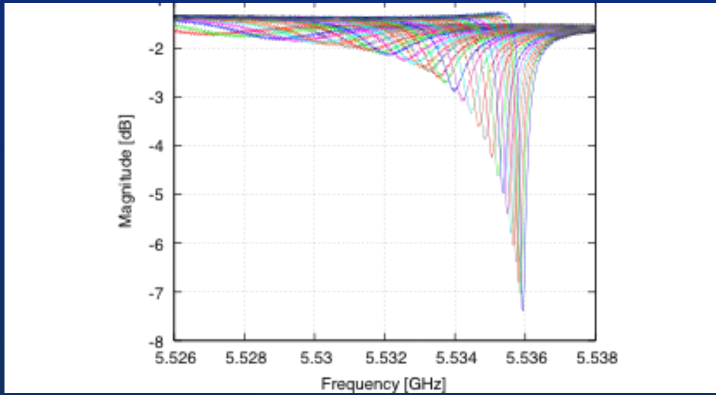


MKID

- Cooper pair breaking detector
  - Millimeter-wave to X-ray
- NEP < 2 x 10^{-18} W/rHz
- Dynamic Range ~ 10^5
- Frequency Multiplexing with a LNA
- Without bias circuit

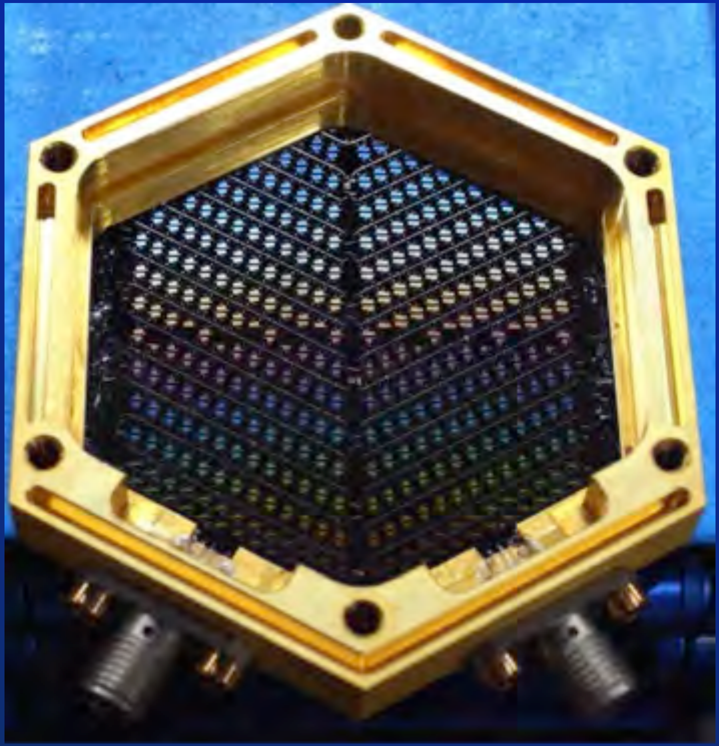
material	Tc [K]	fg [GHz]	Tbath [K]
Al	1.2	88	0.24
Nb	9.3	678	1.9
Ti	0.4	29	0.08
NbTiN	14	1026	2.8
TiN	(0.5) - 4.5	330	0.9

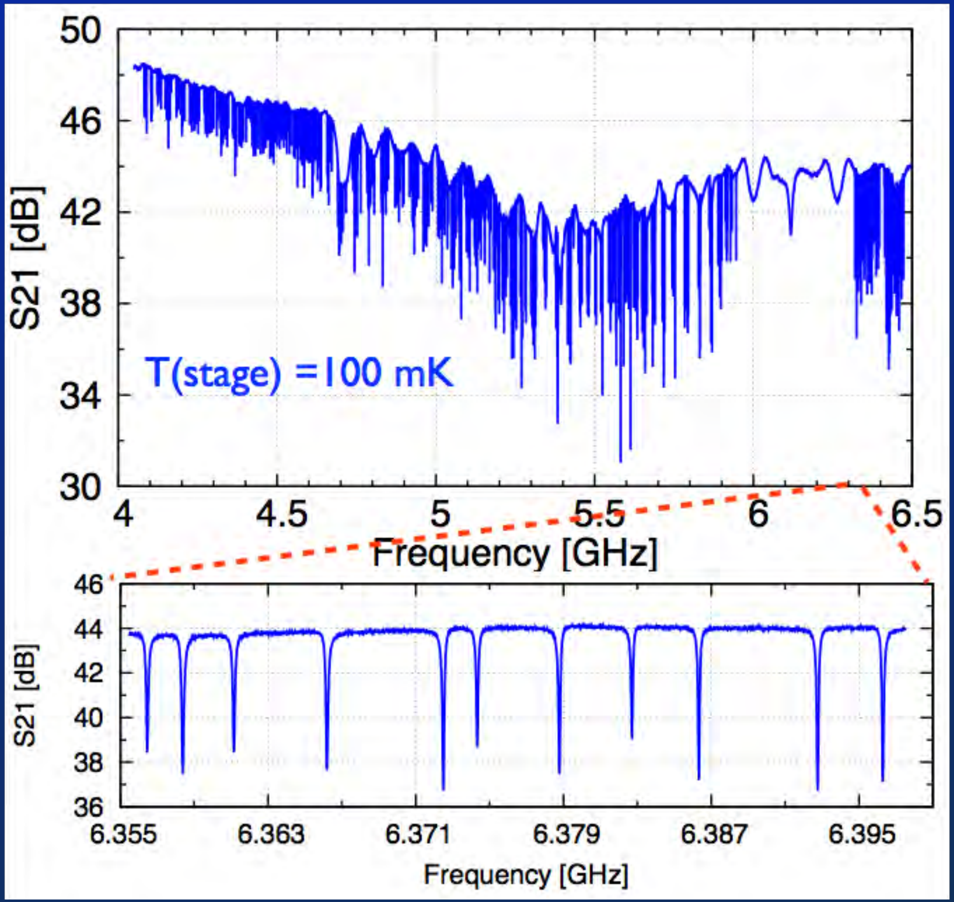
$$f_g = \frac{2\Delta}{h} = 74\ \mathrm{GHz} \times \frac{T_c}{1\ \mathrm{K}}$$



600 pixels MKID

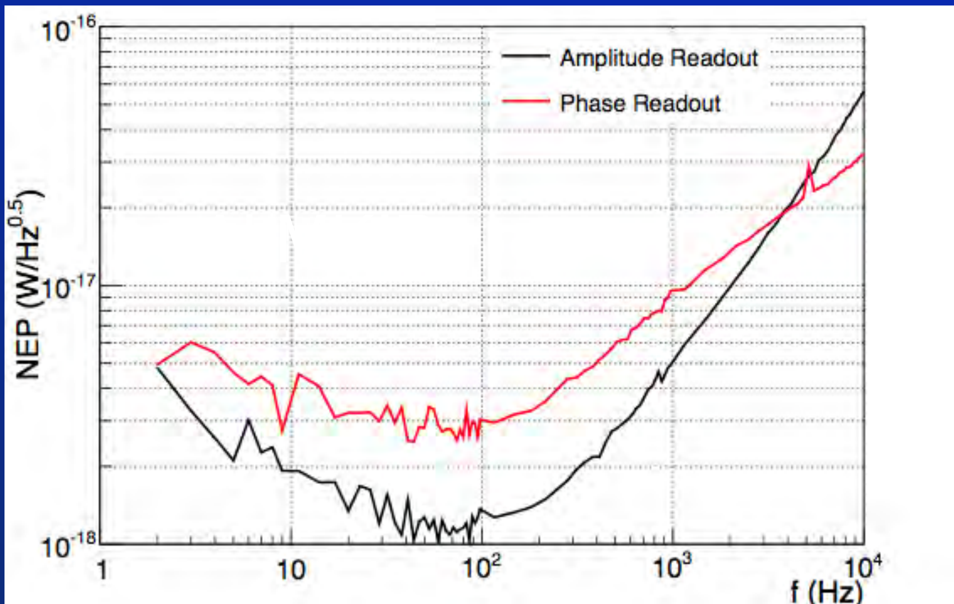
- Aluminum on Si substrate
- 1/4 λ CPW resonators
- 220 GHz double slot antenna
- machined Si lens array



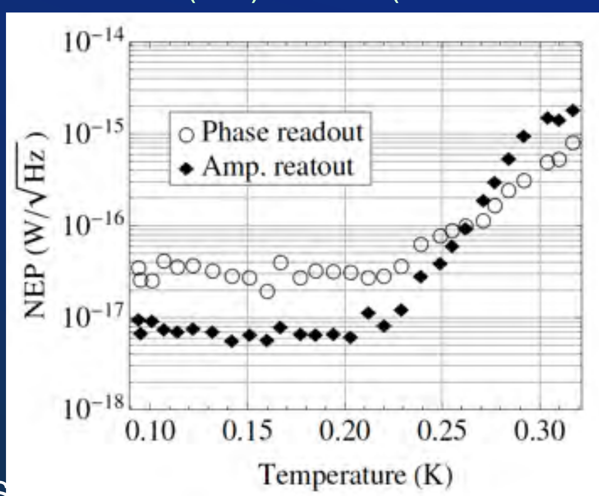


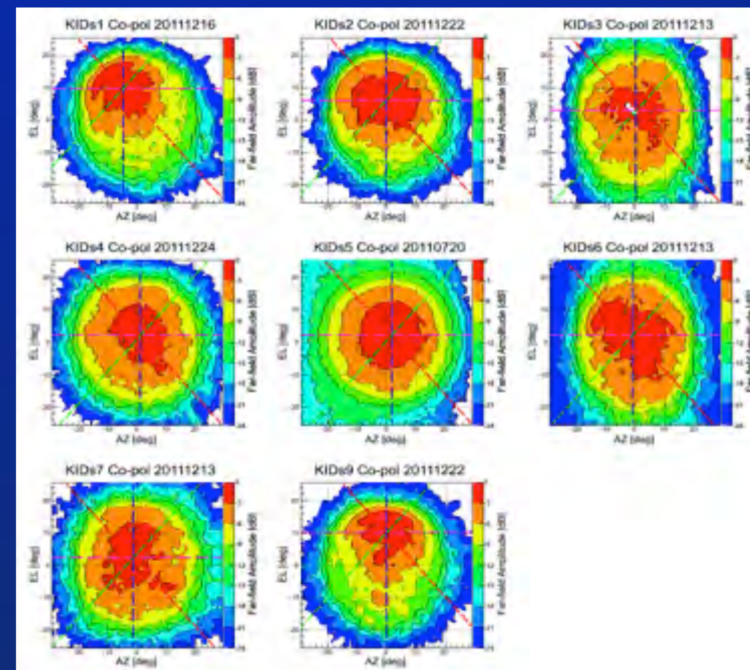
1. Nitta T et al. 2014 “Close-Packed Silicon Lens Antennas for Millimeter-Wave MKID Camera.” J Low Temp 176(5-6):684–90.
2. Sekimoto Y et al. 2014 “Developments of wide field submillimeter optics and lens antenna-coupled MKID cameras” SPIE 91532P
3. Mitsui K, et al. 2015 JATIS “Fabrication of 721-pixel silicon lens array of a microwave kinetic inductance detector camera 1(2):025001

MKID noise and beam measurements at NAOJ



NEP 2 x 10^(-18) W/rHz (Karatsu + 2015 LTD)





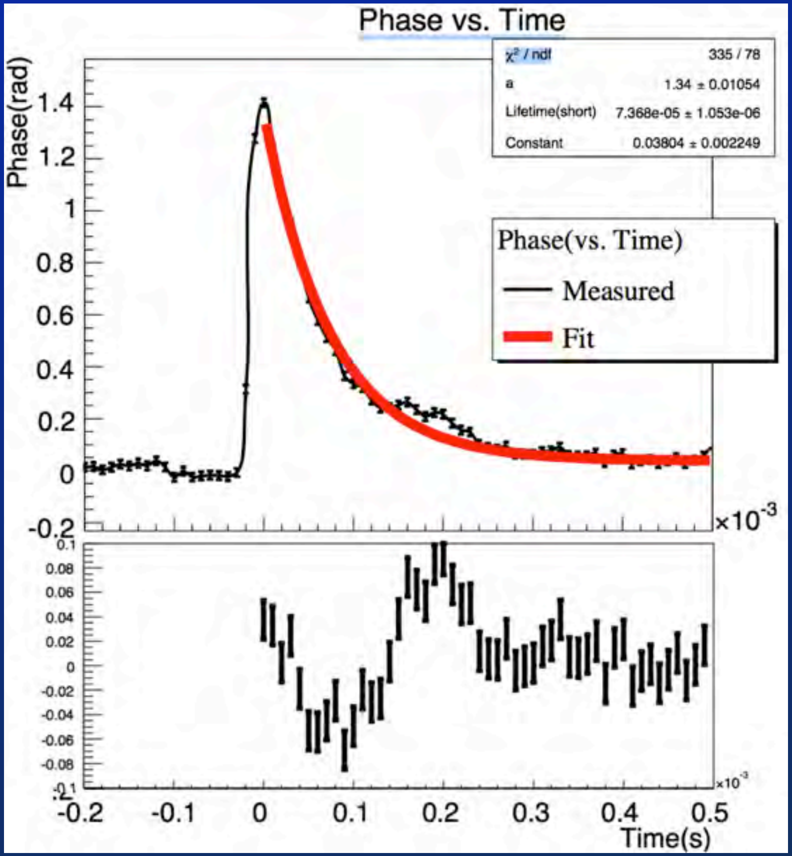
220 GHz beam pattern
T. Nitta + 2013 IEEE TST 3, 56

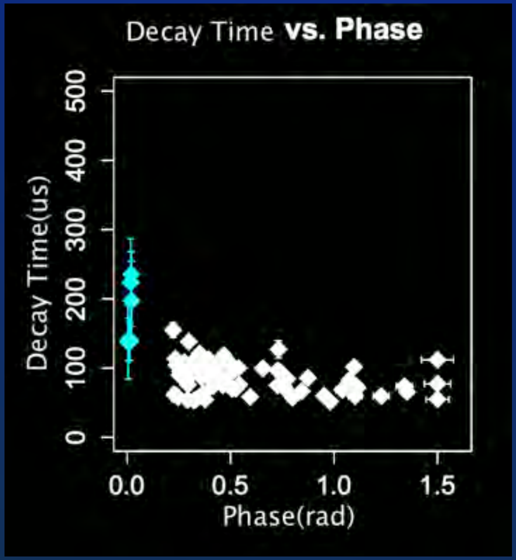
M. Naruse+2013 IEEE TST 3, 180

Cosmic ray events

- Recombination time τ=79.9μs
- 1μs sampling
- Evaluation of superconducting film

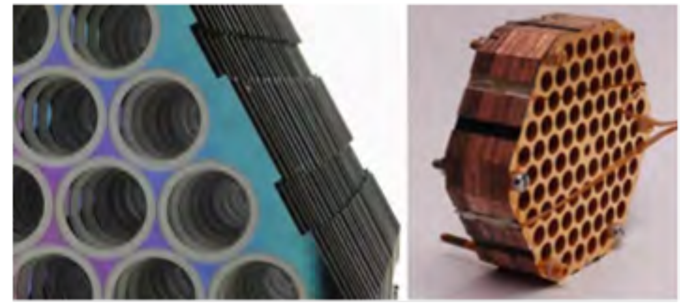
f=3.494GHz





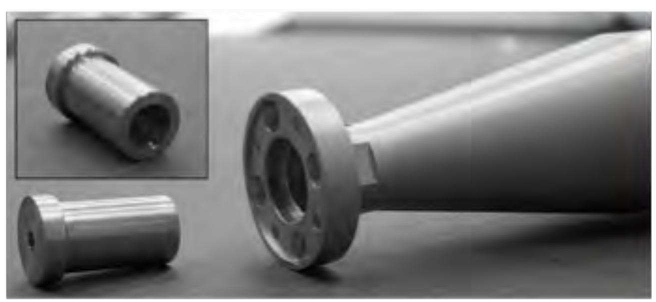
Corrugated Horn Array

1. Platelet/Stacked
    1. Si platelet (J. Nibarger + 2012)
        1. Ring Loaded (J. McMahon + 2012)
    2. Al stacked (F. Del Torto + 2011)
    3. Al stacked (L. Lucci + 2012)
2. Direct Machining
    1) 2 sections (ALMA Band4)
    2) 4 sections (WMAP W-band)

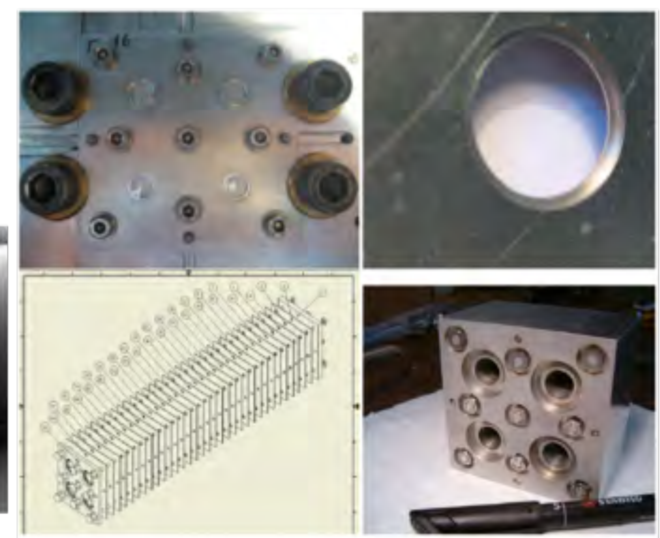


123 – 174 GHz (J.P.Nibarger et al., 2012, J Low Temp. Phys.)

K. Kimura et al. 2008 IJMTW



125 – 163 GHz
(K.Kimura et al., 2008, J Infrared Millim. Terahertz Waves)

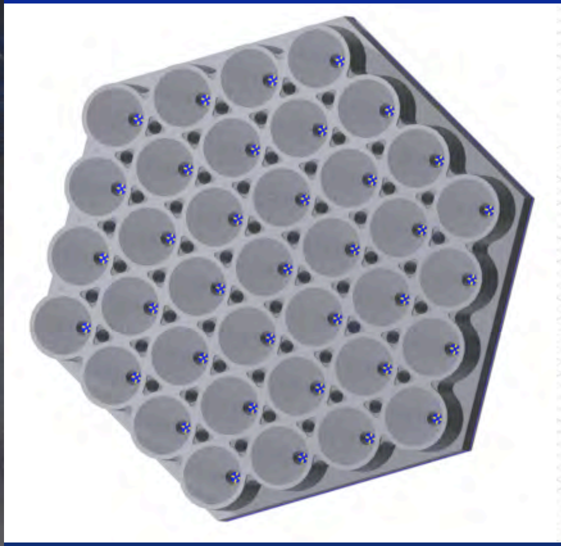
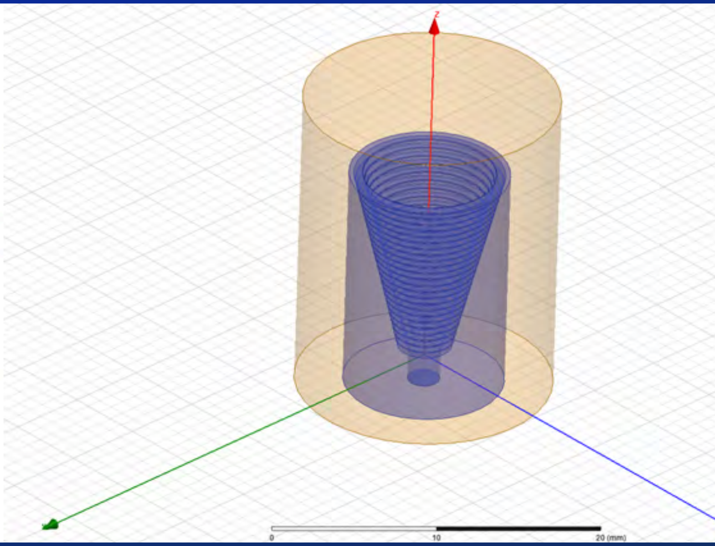


75 – 111 GHz (F.D.Torto et al., 2011, J Instrum.)

L. R. Lucci et al. 2012 IEEE AWPL11,1162

Direct machined corrugated horn array

1)Larger effective area than platelet/stacked horn without fixing bolts
2)Lighter weight by carving unnecessary part
3)Low standing wave with chamfer
4)Superconducting electro-magnetic shield

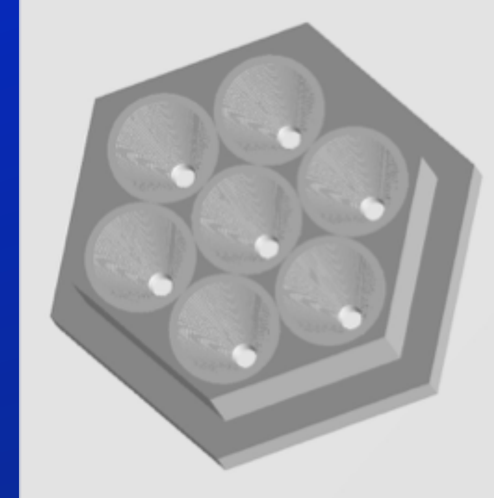
Octave-band corrugated horn design

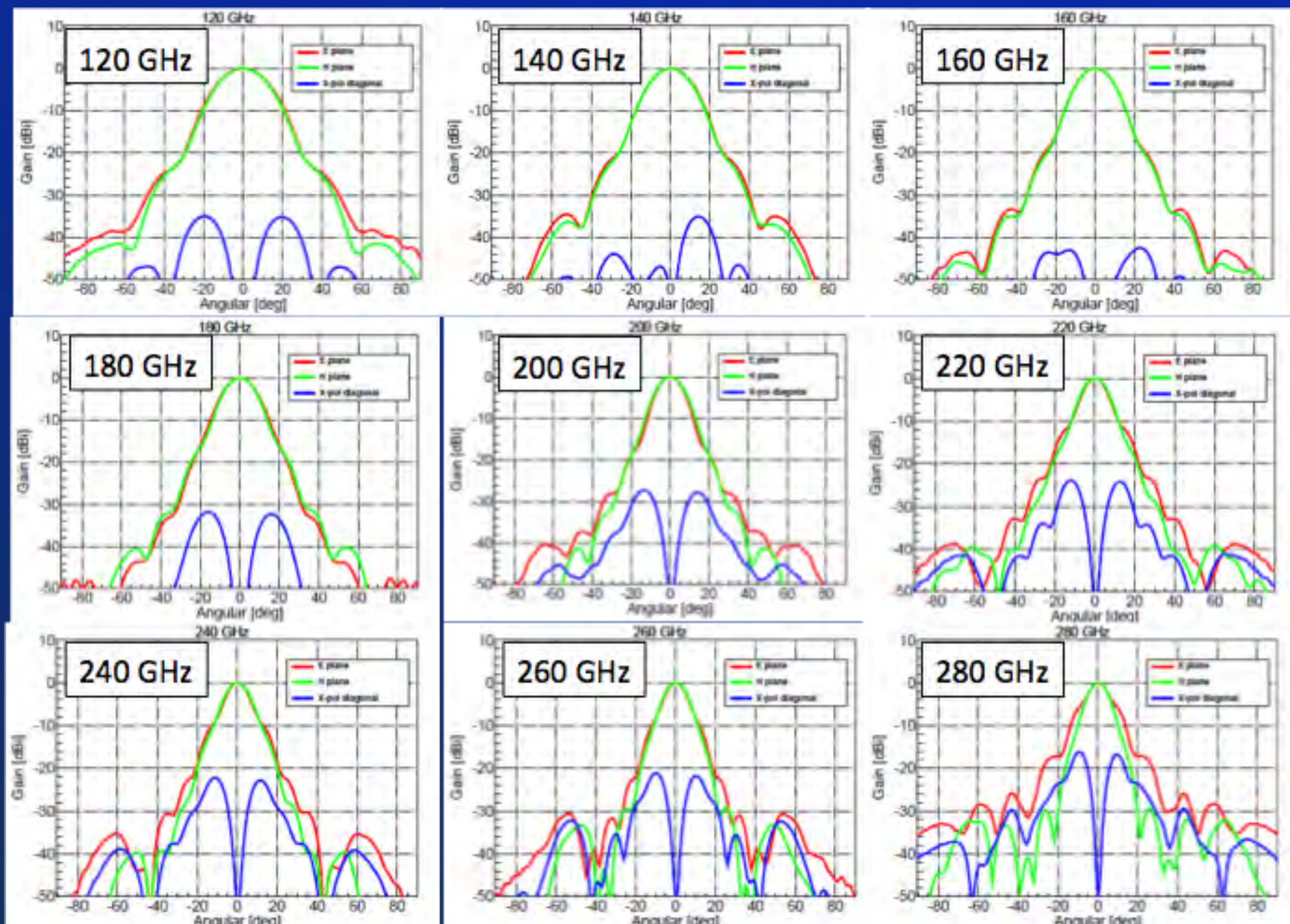
Broadband 118 - 280 GHz BW 1 : 2.3

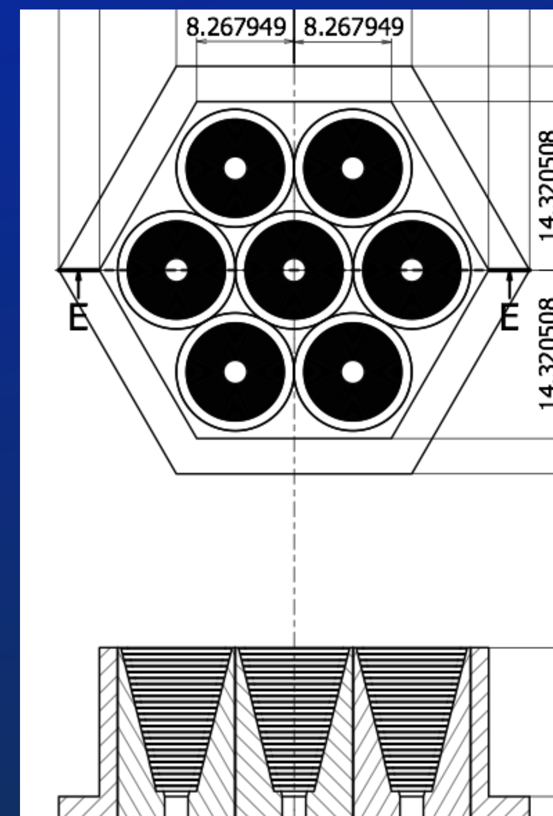
Direct Machining from Al block

Constant spacing of corrugations

S. Sekiguchi et al. 2015 LTD



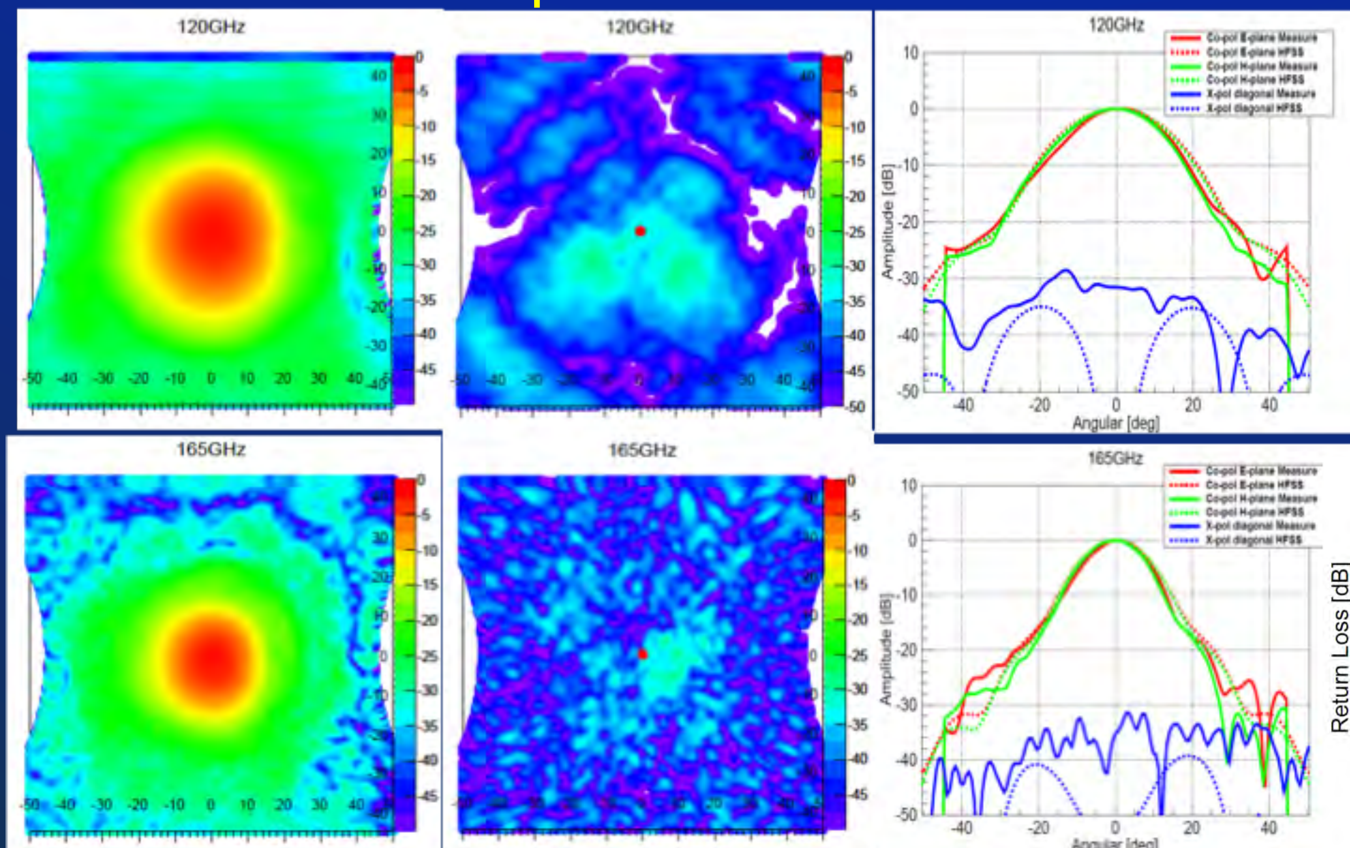


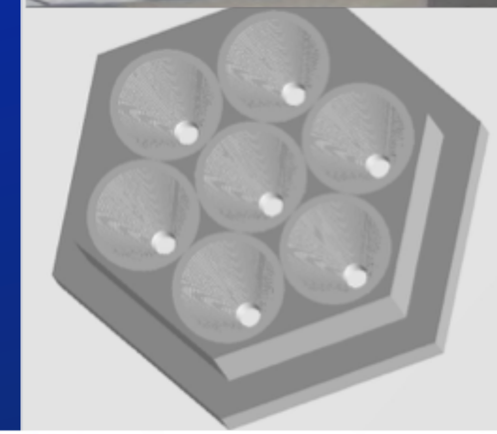


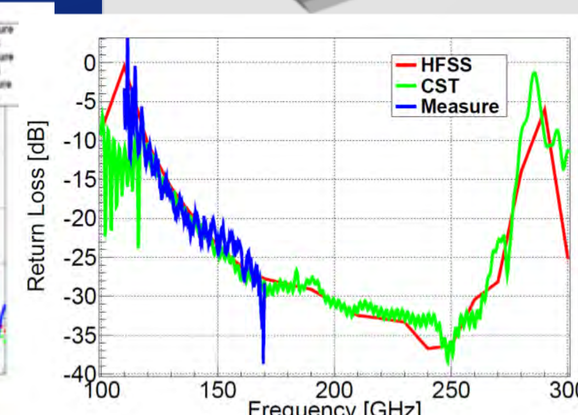
Octave corrugated horn array Beam Measurements

120 – 280 GHz

room temperature measurements

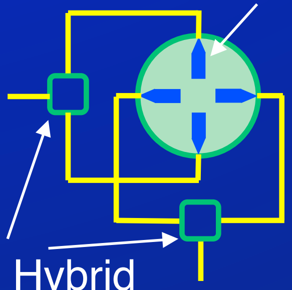






S. Sekiguchi et al. 2015 LTD

Planar OMT with circular waveguide



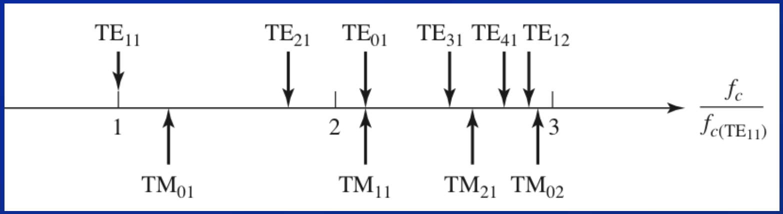
G. Engargiola & R. Plambeck 2003 RSI 74, 1380

Fundamental Mode: TE11(Odd mode)

Higher Modes: TM01 TE21 TE01 TM11 (Even modes)

are cancelled with 180° Hybrid

P. Grimes + 2007 Electron Lett 43(21):1146.

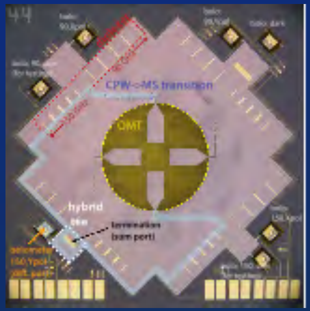


David Pozer Microwave engineering

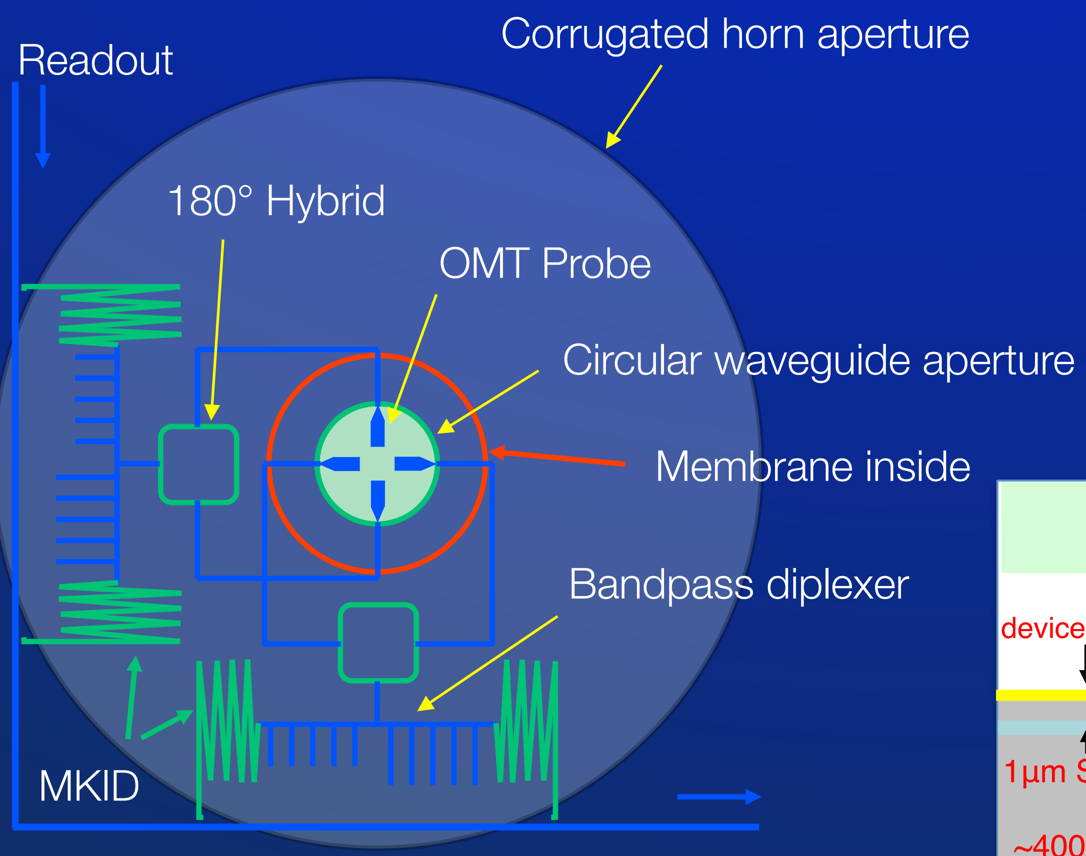
Broadband OMT (80 - 160 GHz)

J. McMahon + 2012 JLTP 167, 879

R. Datta + 2014 JLTP 176, 670

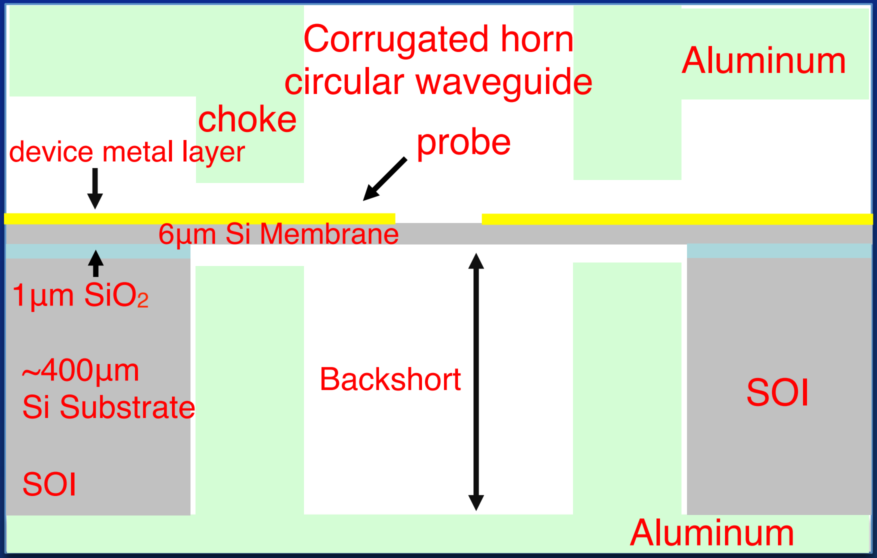


Planar OMT on SOI

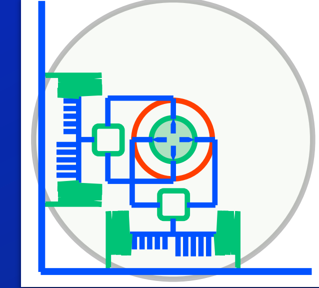


S. Shu+2015 LTD

1. OMT Probe 80 - 160 GHz
2. 180 degree Hybrid : CPW
    1. 80 - 160 GHz
    2. C.-H. Ho + 1994 IEEE MTT 42, 2440
3. CPW —> microstrip (MS)
4. Diplexer and bandpass filters : MS
    1. Bandpass stub filters
    2. J. McMahon + 2012 JLTP 167, 879
5. MS —> CPW MKID
    1. P. Day + 2006 NIM PR-A 559, 561

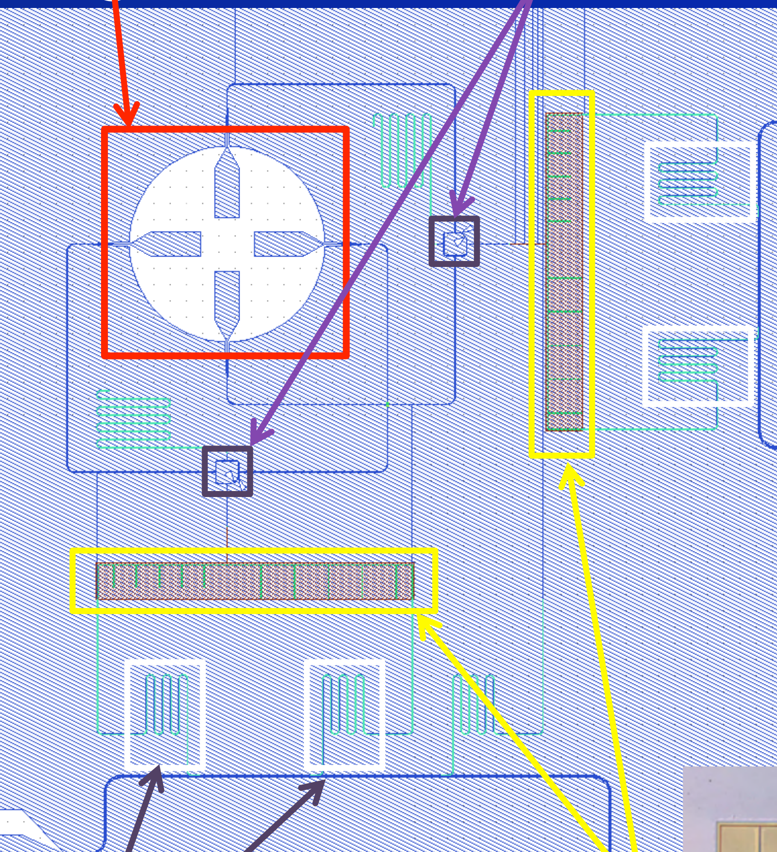


OMT-MKID

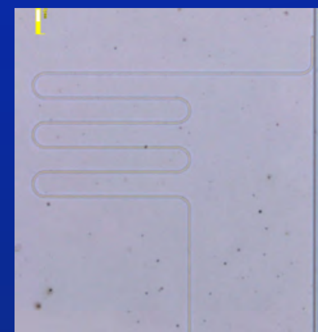


OMT

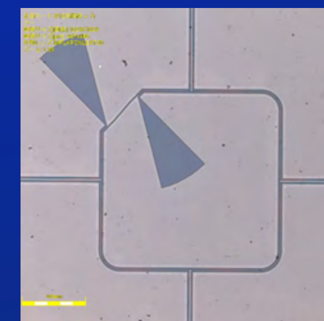
180°coupler



CPW Al MKID

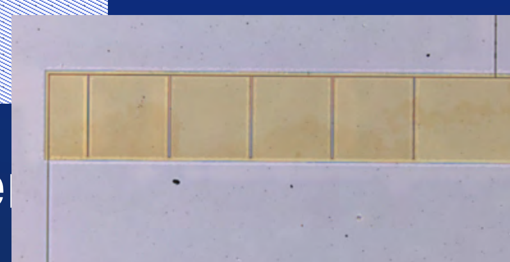


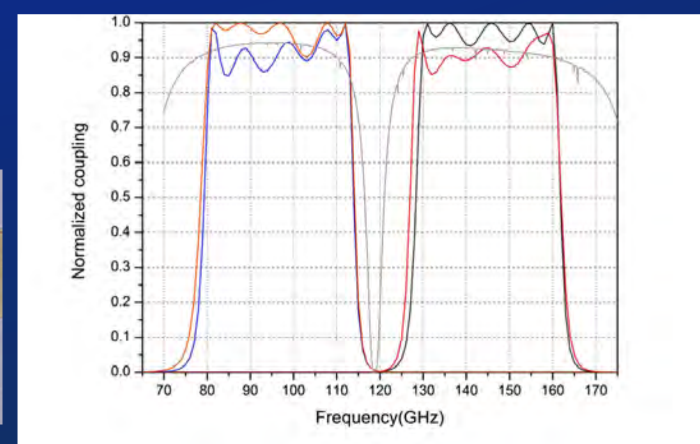
CPW 180° hybrid



Band shapes are defined by planar filters

MS stub filter



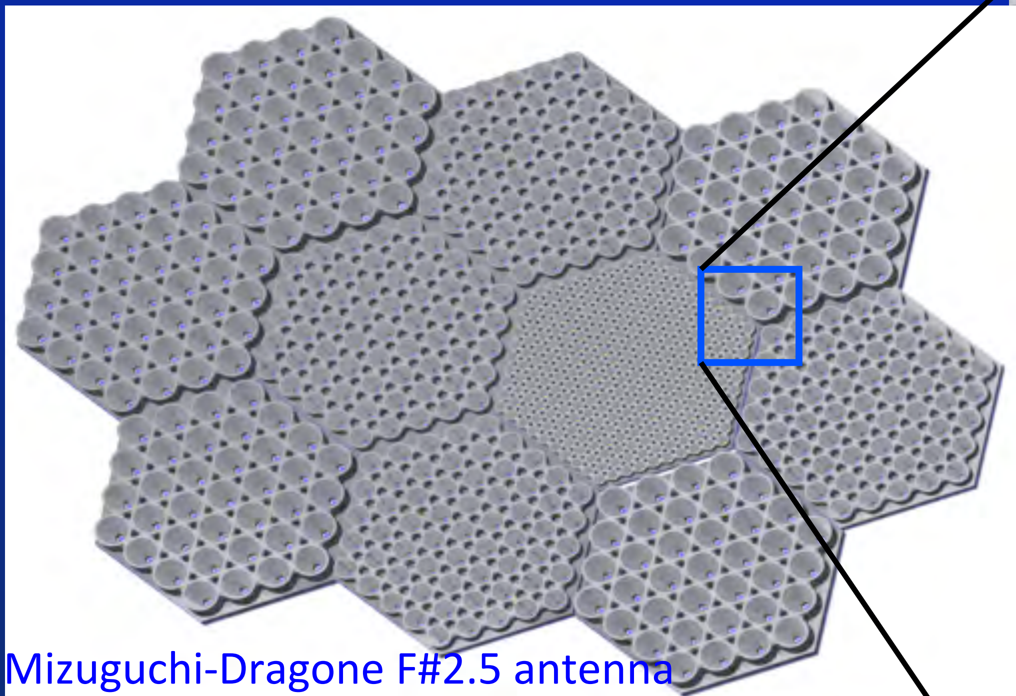


Bandpass filter

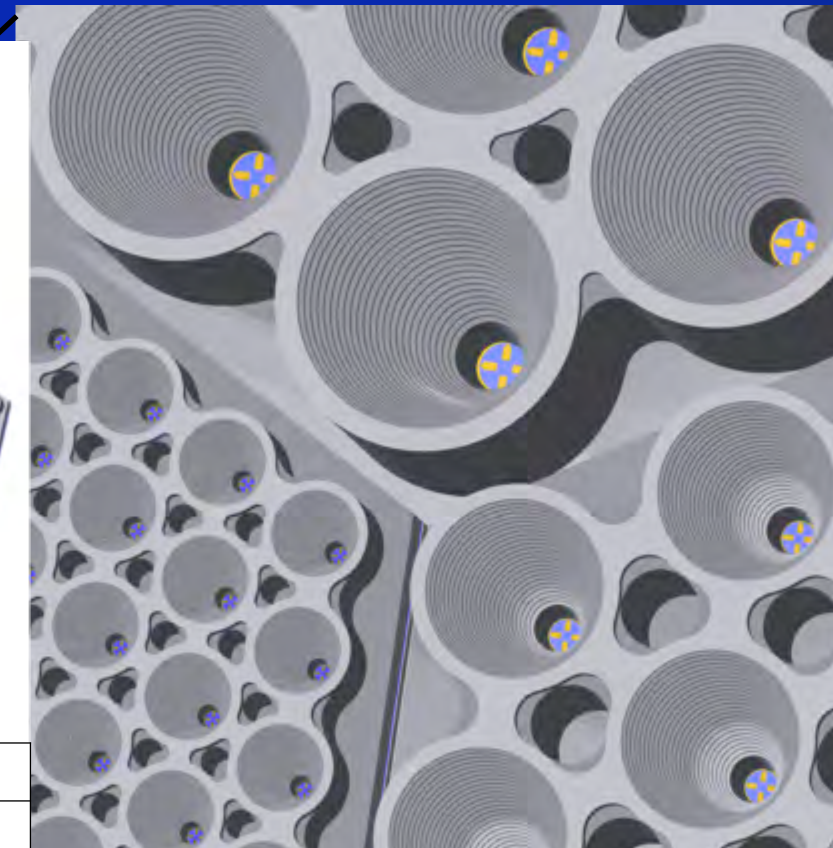
MKID

S. Shu + 2015 LTD

MKID focal plane for LiteBIRD



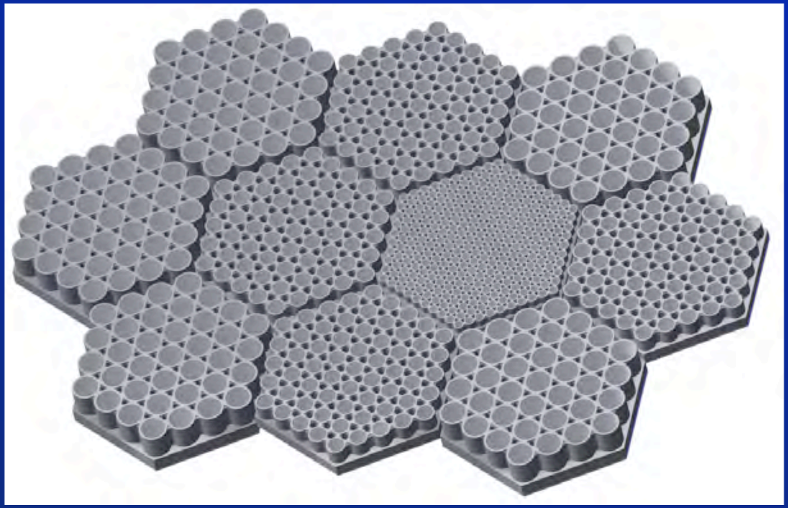
Mizuguchi-Dragone F#2.5 antenna



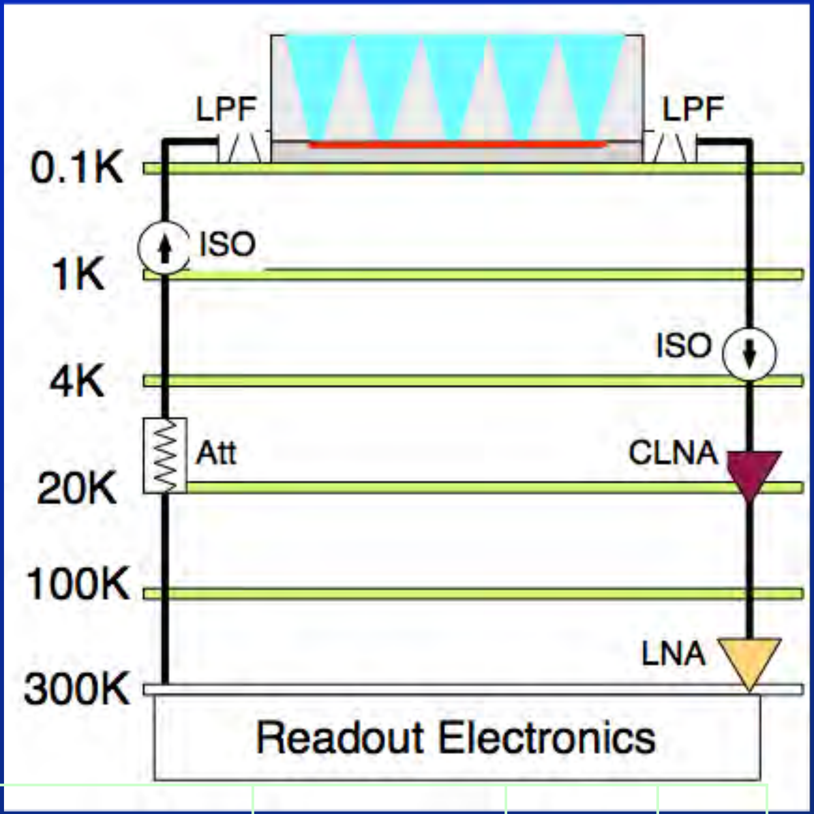
	Pixel	Pixel	module	detector	low	high	BW
	[mm]	Num	Num	Num	GHz	GHz	%
Low	24	36	5	360	55	77	33%
				360	78	108	32%
Mid	16	61	4	488	80	113	34%
				488	117	160	31%
High	8	271	1	542	165	227	32%
				542	233	330	34%

Total weight ~ 8 kg

Thermal Calculation



20 coaxial cables



		Radiation	Conduction	Disspation	sum	unit
100 mK	MKID+Feed	0.77	0.32	0.19	1.78	uW
100 mK	structure		0.5			uW
1 K	Thermal anchor		17.4	0.75	18.2	uW
4 K	Thermal anchor		467	3.8	471	uW
20 K	HEMT (10) amplifiers			40	40	mW

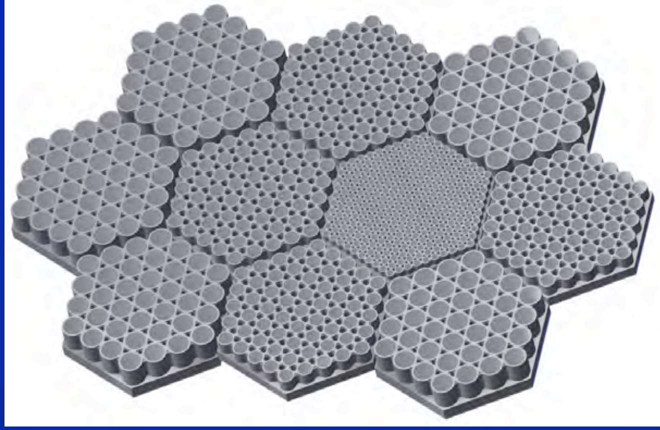
Challenges

- Low frequency MKID: 50 – 90 GHz
  - Ti/Al bilayer (Catalano + arxiv1504.00281)
  - TiN/Ti multilayer (Hubmayr + 2015 apl 106, 073505; Bueno + 2014 apl 105, 192601)
  - AlMn [D. Moore 2012]
  - Al/Cu bilayer (A. Dominjon + 2015: Poster)
- 1/f noise
  - knee 0.01 Hz
- Space qualified readout
- Mitigation of cosmic rays
  - D'Addabbo + arxiv1505.01647
- High optical efficiency
  - Horn-planar OMT/bandpass filters
  - For TES; Datta + 2014 JLTP 176, 670

MKID関連の発表

関本裕太郎	国立天文台	LiteBIRD焦点面MKID検出器の開発
木村公洋	大阪府立大	GRASPを用いたCMB観測LiteBIRD衛星光学系の検討
美馬覚	理化学研究所	GroundBIRD焦点面検出器アレイの開発
新田冬夢	筑波大学	野辺山 45m 電波望遠鏡搭載に向けた90/150-GHz帯MKIDカメラの開発
久松俊輔	筑波大学	野辺山 45m 電波望遠鏡搭載用MKIDカメラの観測システムの開発
Poster		
井上将徳	大阪府立大学	CMB観測LIteBIRD衛星クロスドラゴン型アンテナのビームパターン計算およびスケールモデル実験

Summary



- MKID focal plane for LiteBIRD
  - Octave bandwidth Corrugated horn array
  - OMT - MKID

Acknowledgement
Jochem Baselmans, Akira Endo, J. Gao and LiteBIRD working group