MKID Camera for Nobeyama 45-m Radio Telescope

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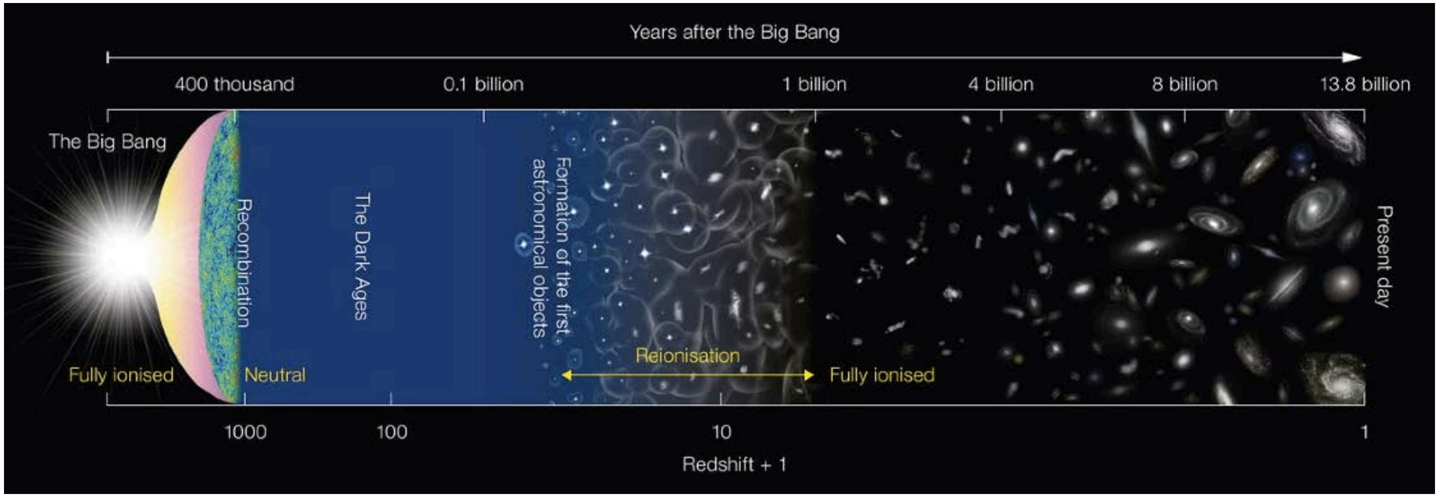
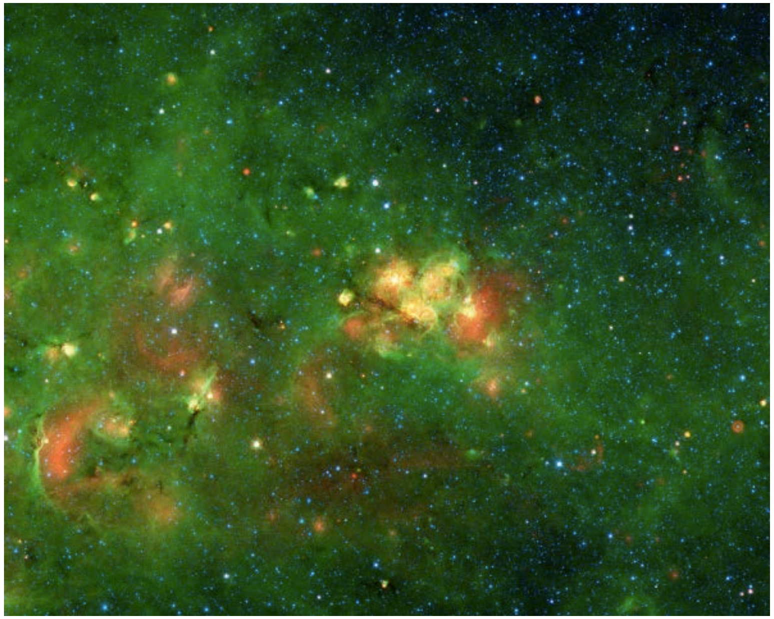
Galaxy Evolution and Star Formation



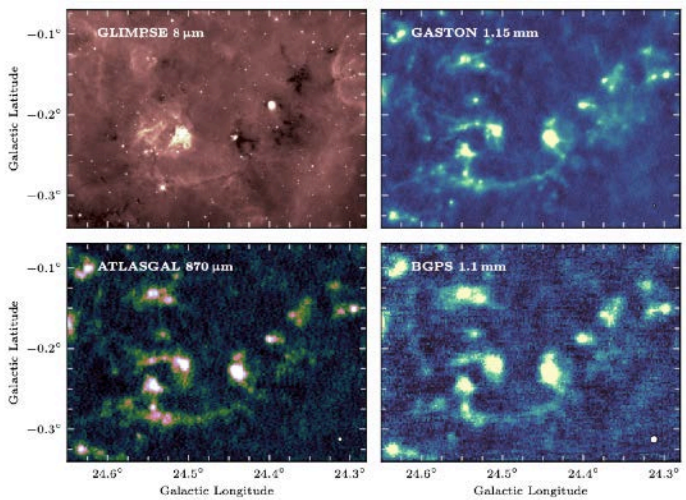
Credit: NAOJ

- How did galaxies form and evolve in the Universe?
- How are stars forming in the local Universe?

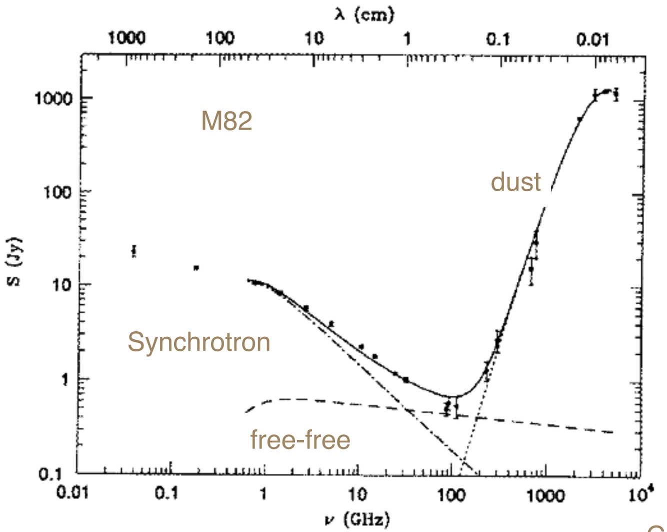


Credit: NASA/JPL-Caltech/Univ. of Wisconsin

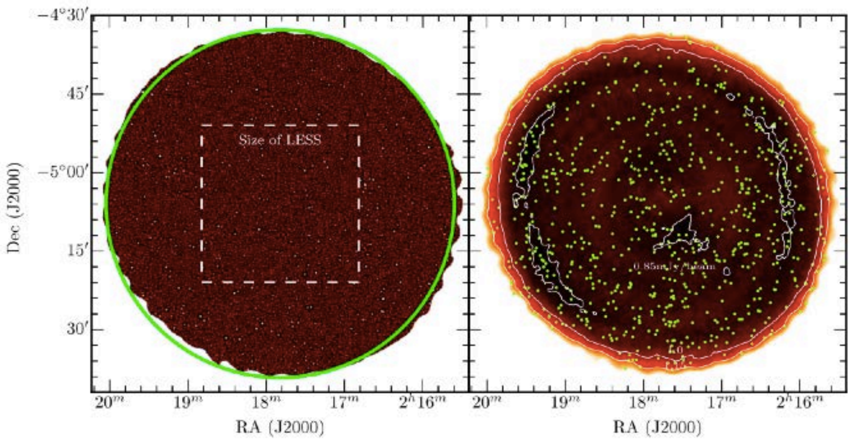
Radio Continuum Emission from ISM & Galaxies



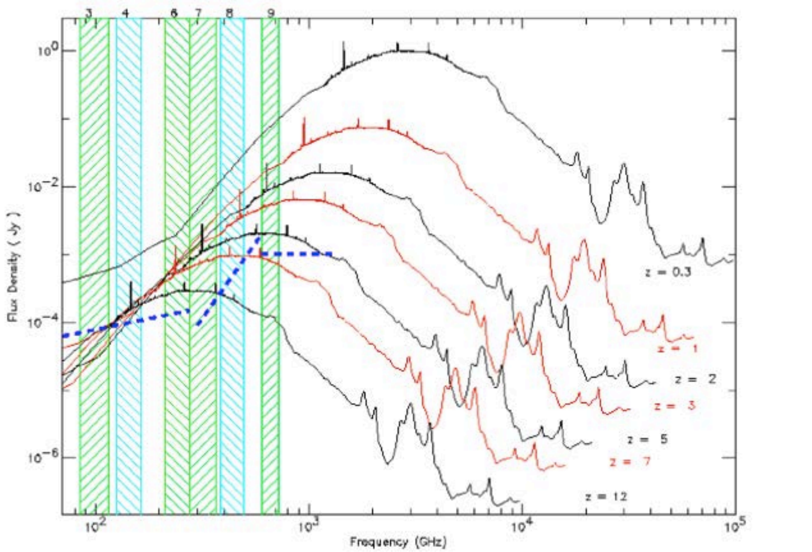
NIKA2, Rigby+20



Condon92



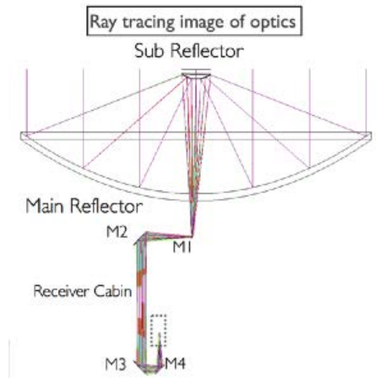
SCUBA2, Chen+16

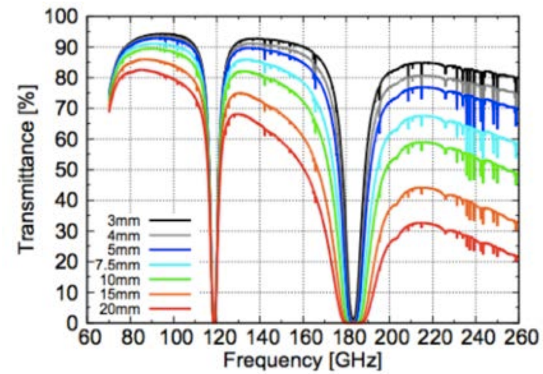


M82 from ISO, Beelen and Cox

- Wide-field surveys reveal the distribution of the source.

Nobeyama MKID Camera for 100-GHz Band





Calculation by S. Ishii

Observation Frequency	90--110 GHz (Center : 100 GHz)
Field-of-View	~ 3 arcmin
Polarization	linear single polarization
Detector	Microwave Kinetic Inductance Detector (MKID)
Cold Optics	Refractive optics with two Si lenses
No. of Pixels	109 pixels
Focal Plane Temperature	< 200 mK
Beam Size	~ 16.5″ @100 GHz
Sensitivity (NEFD)	＜30 mJy √s （Goal） ＜100 mJy √s （Minimum）

Collaboration for Nobeyama MKID Camera

UTsukuba
Tom Nitta ★
Yosuke Murayama ★
Hiromu Miyazawa ★
Ryohei Noji ★
Miwa Aoki
(alumni grad/undergrad students)
Nario Kuno

NAOJ Facilities

Nobeyama Radio Observatory (NRO)

Advanced Technology Center (ATC)

NAOJ
Makoto Nagai
Hiroshi Matsuo
Hitoshi Kiuchi
Wenlei Shan

JAXA
Yutaro Sekimoto

Saitama U.
Masato Naruse

UEC
Takashi Noguchi

Kwansei Gakuin U.
Naomasa Nakai

LEKID Array

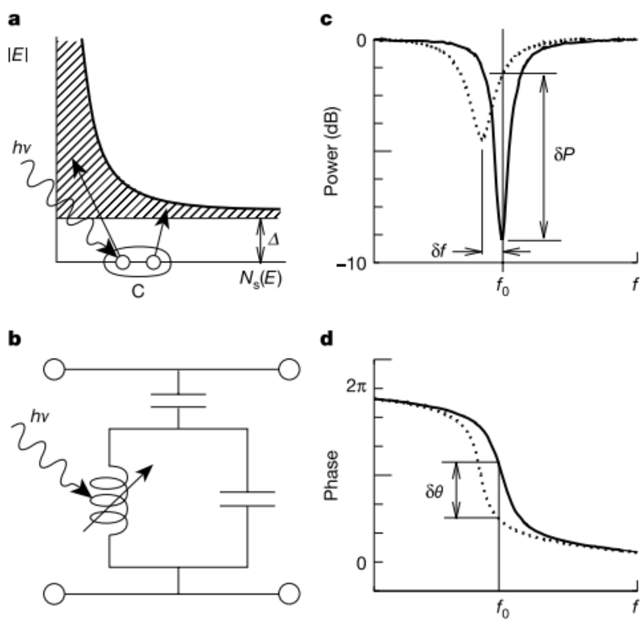
Institut Néel
Alessandro Manfardini
Johannes Goupy
Martino Calvo

LPSC
Juan Macias-Perez
Andrea Catalano

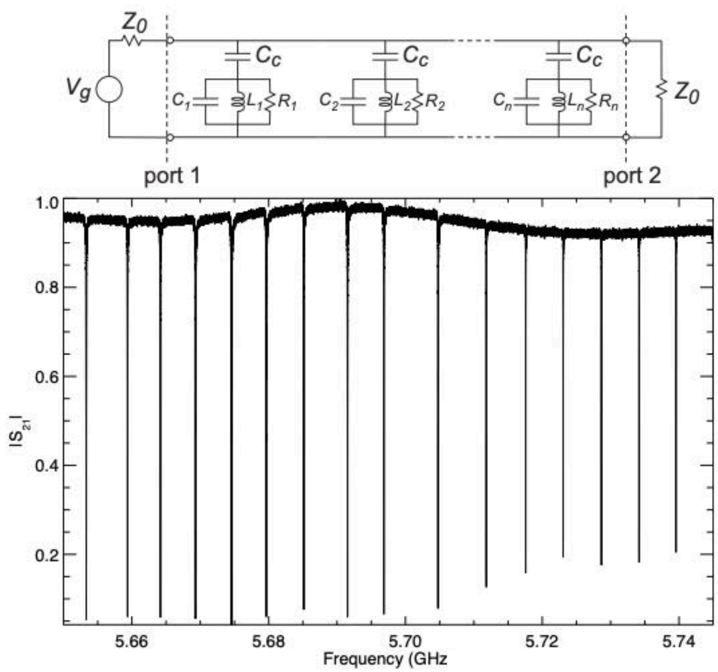
★ main members for the 3rd commissioning operation

Microwave Kinetic Inductance Detector (MKID)

- Resonator of supercondicting films coupled to a throughline
- Suitable for large detector arrays
  - high sensitivity
  - frequency-domain multiplexing



Day+03



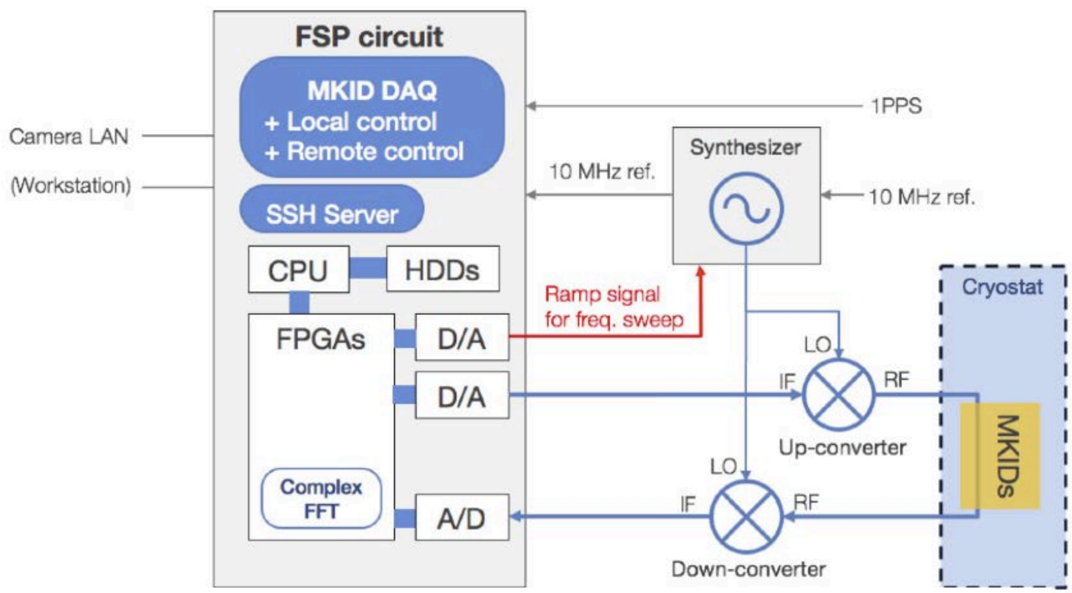
Mazin+12

MKID Readout

- Measures transmission ‘S_{21}’ both amp. & phase.
  - generates probe tones (PTs), acquires returned PTs

“multi-tone VNA”

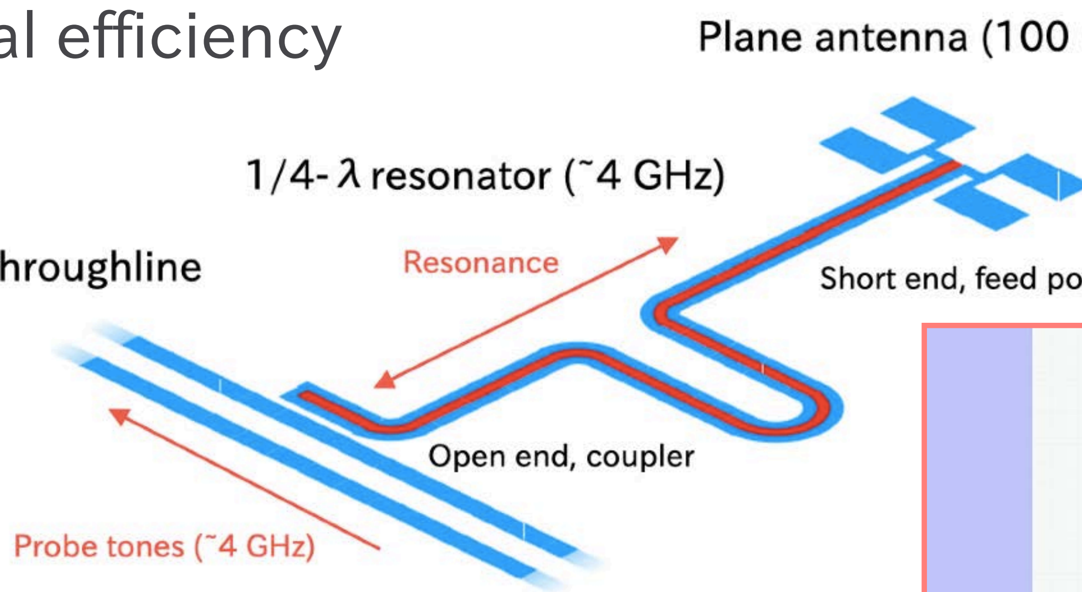
- Digital signal processing
  - Fast Fourier Transform Spectrometer (FFTS)
  - Direct down conversion (DDC)
  - FFTS + frequency sweeping (FS)

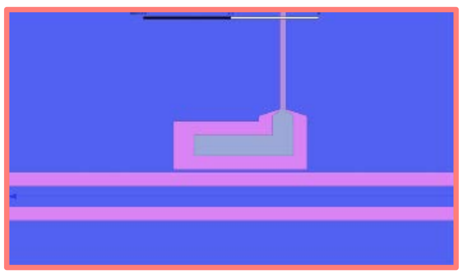


Fequency sweeping scheme (Nagai+18)

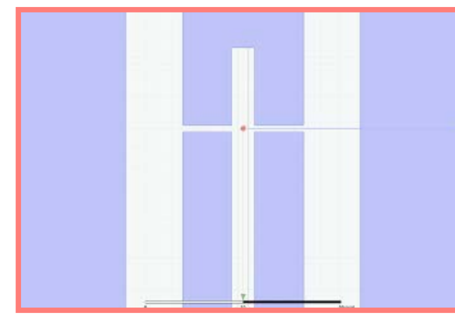
Antenna-coupled KID Design

- NbTiN/Al-hybrid MKID (Yates+11)
  - ✔ high optical efficiency

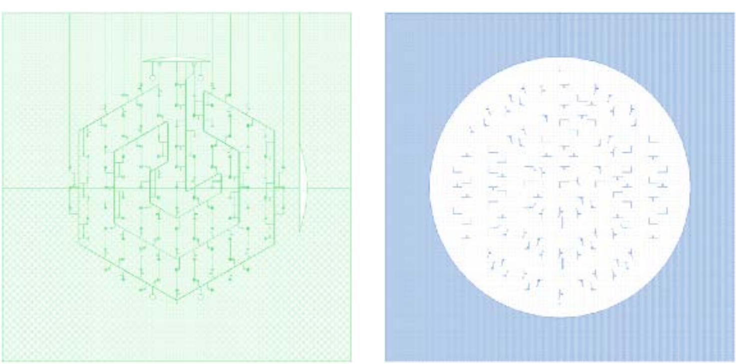




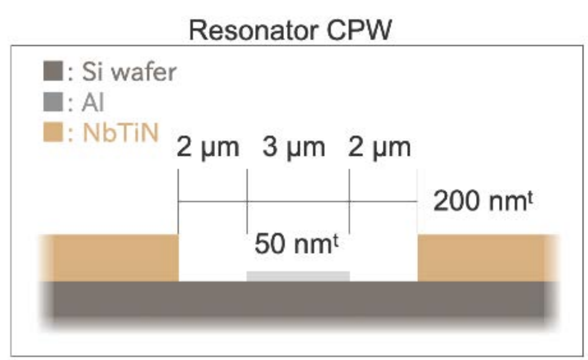
Coupler



Feed point

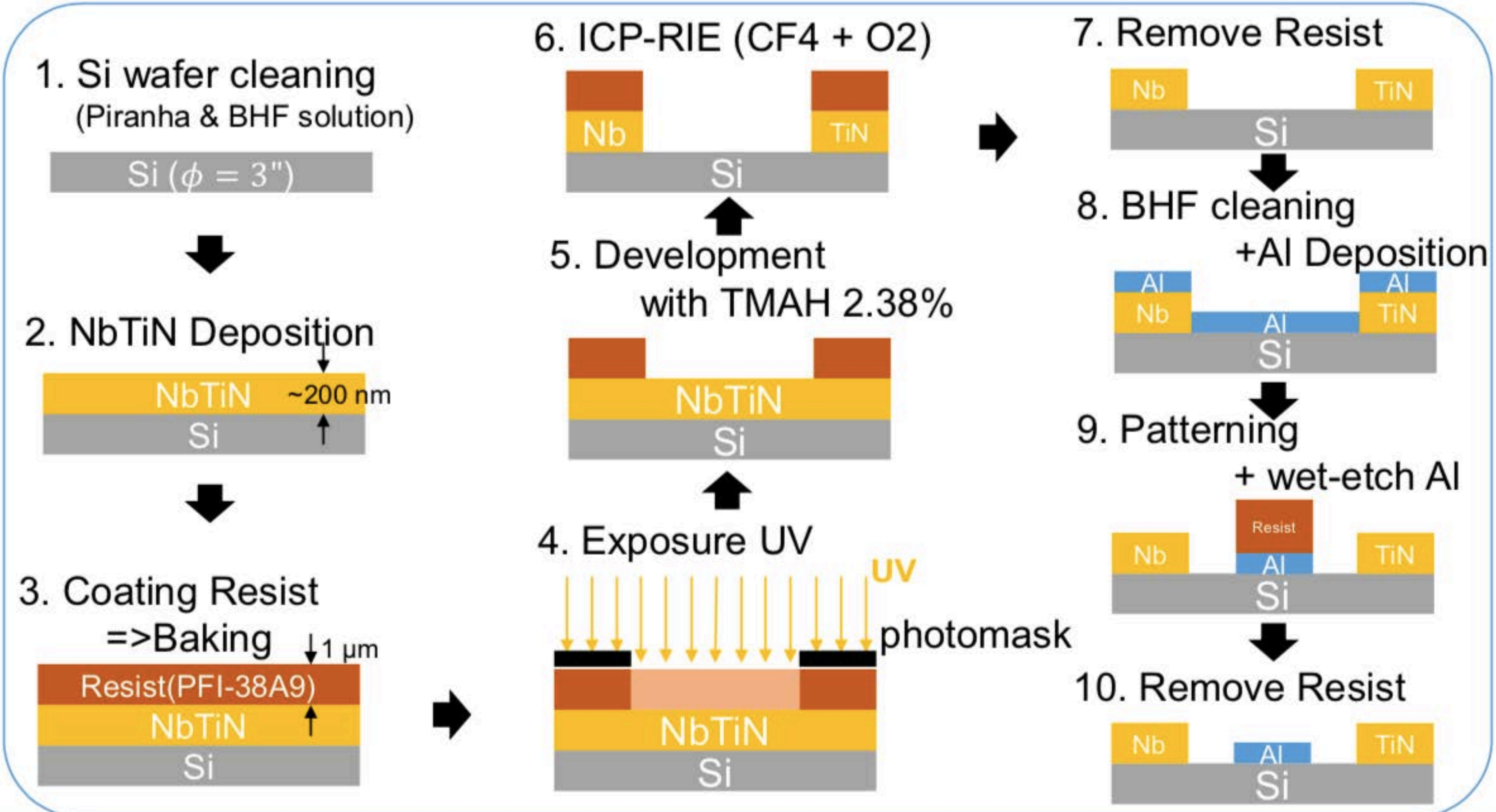


Array mask pattern



Fabrication of NbTiN/Al-hybrid MKID

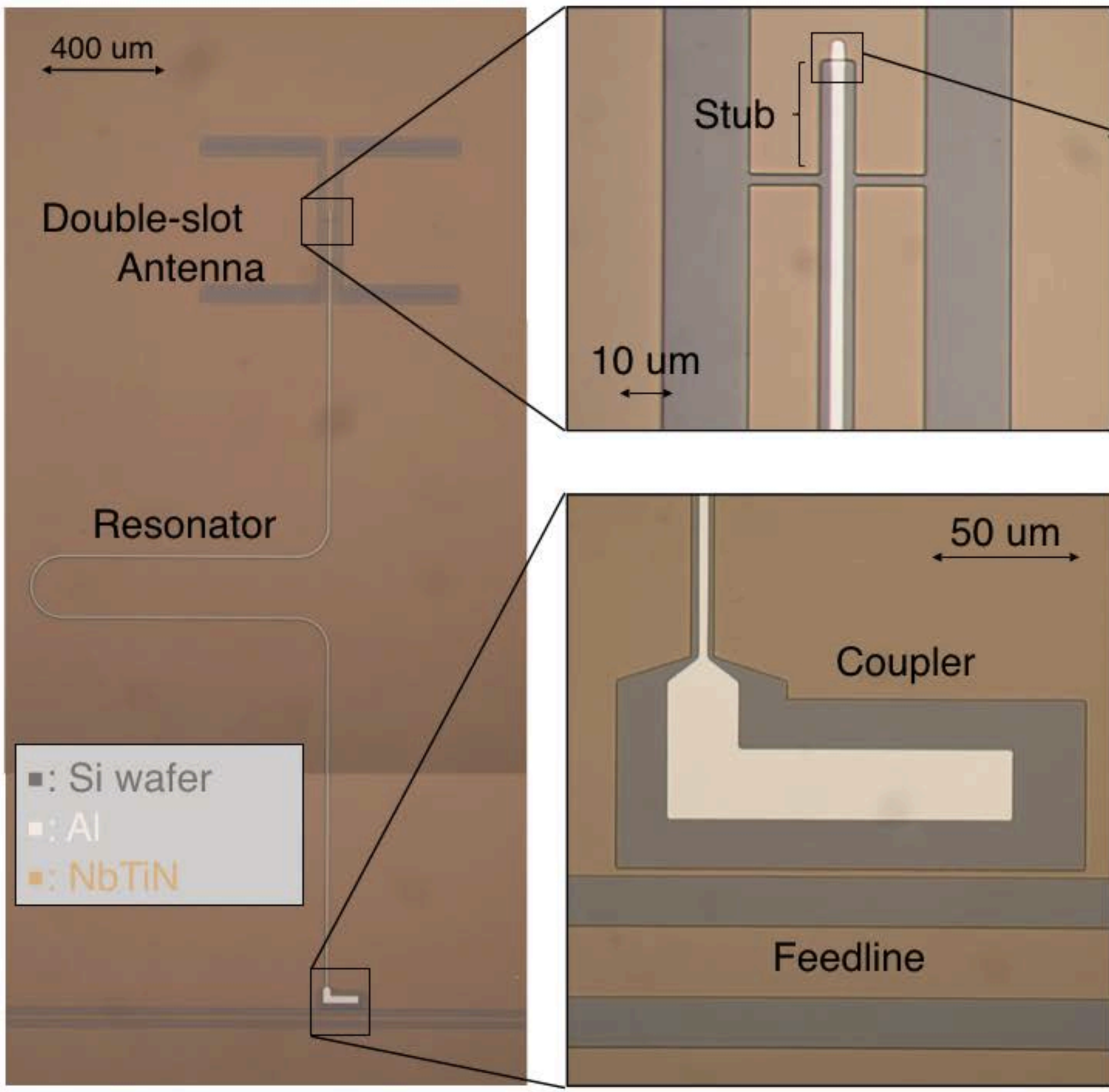
@ ATC clean room



Fabrication of NbTiN/Al-hybrid MKID

SEM Image of a detector pixel

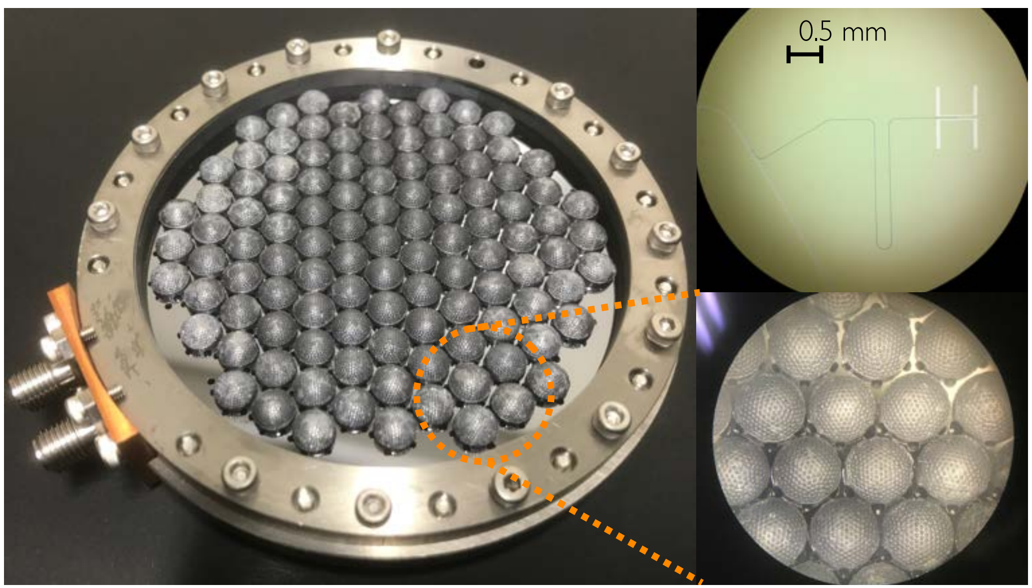
Fabrication of NbTiN/Al-hybrid MKID



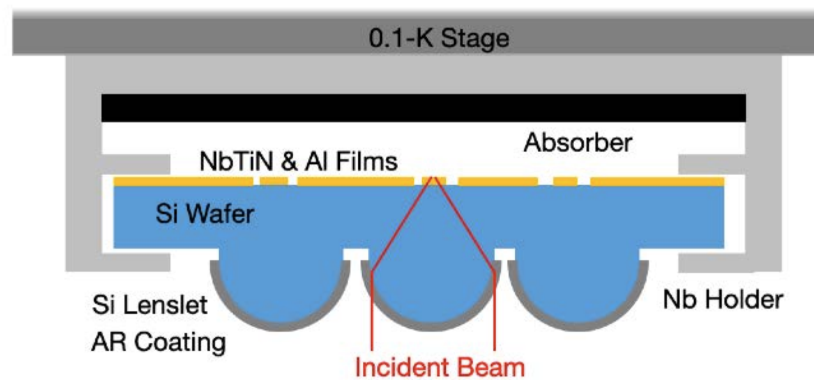
SEM Image of Al/NbTiN contact

Focal Plane Array

- MKID: NbTiN/Al-hybrid, 109pixels, 3-inch Si wafer
- Si lens array: anti-reflection (AR) (Stycast & glass beads)
- Device holder: made of Nb, closed

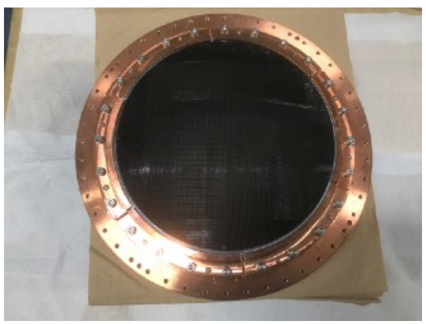


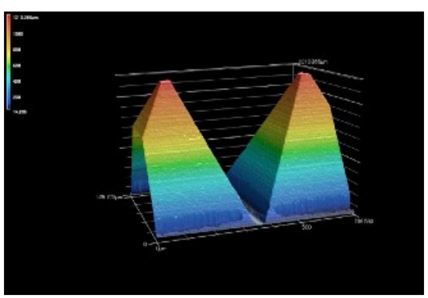
Focal plane array



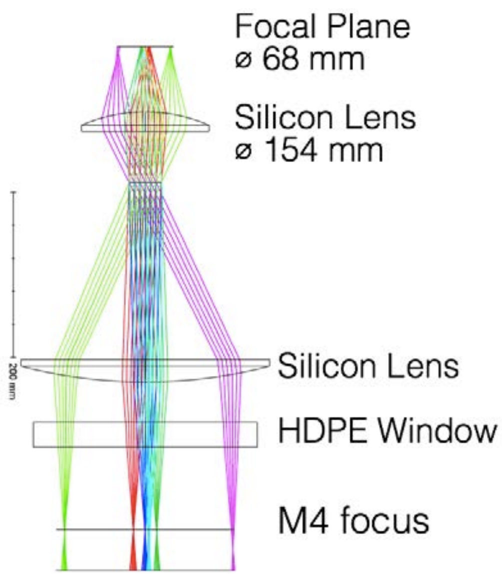
Camera Cryostat

- Dilution refrigerator + GM2 refrigerator
- Cold optics
  - Si lens w/ AR structure
  - Metal mech filters: 3 LPFs
  - IR filters: PTFE, RT-MLI

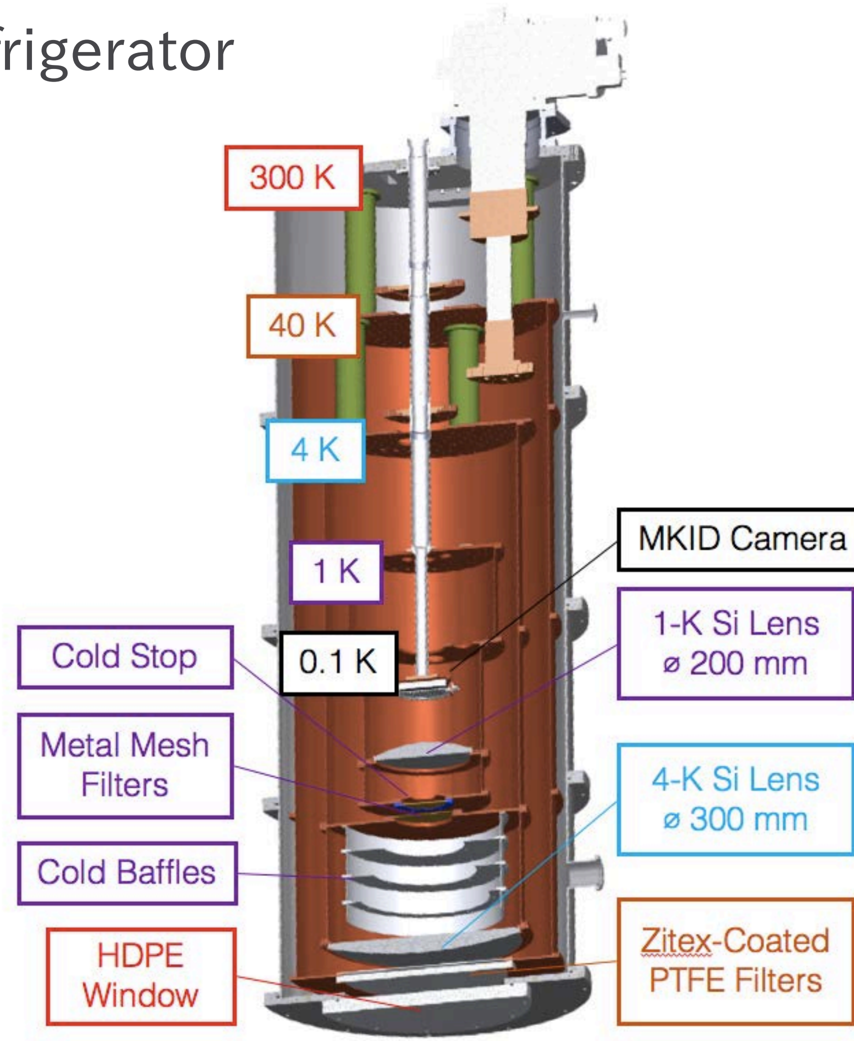




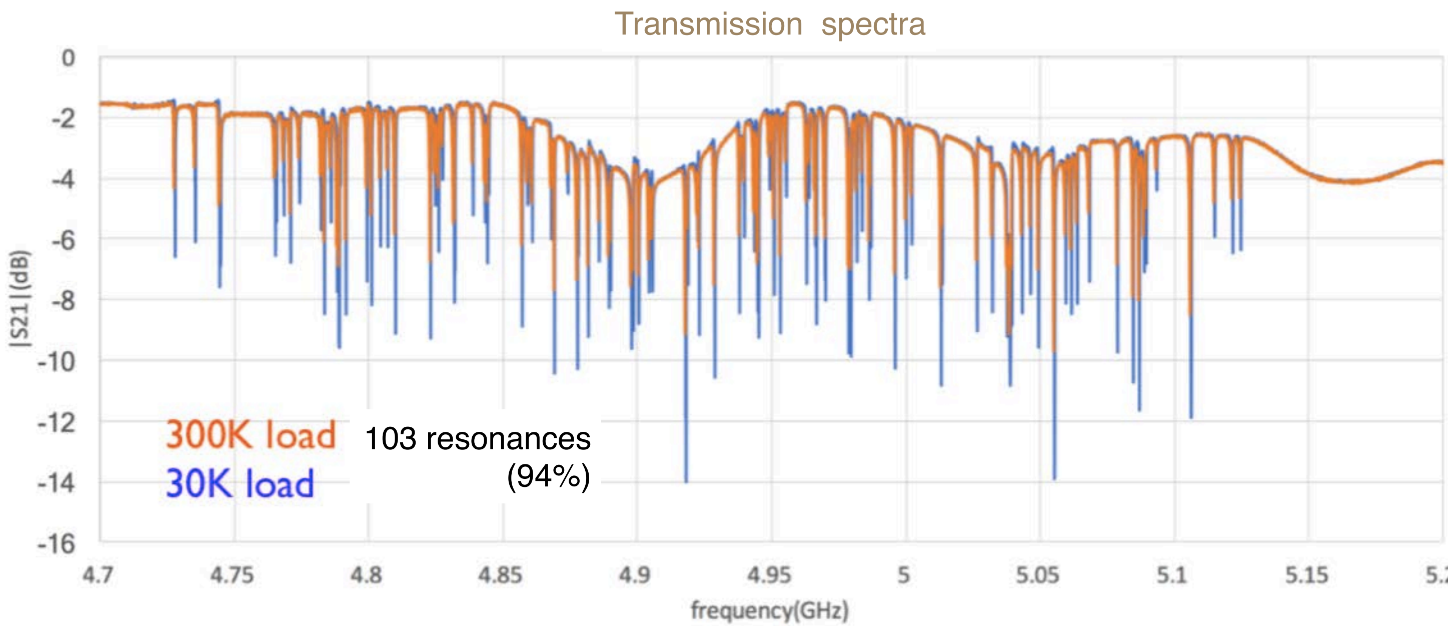
AR on Si lens

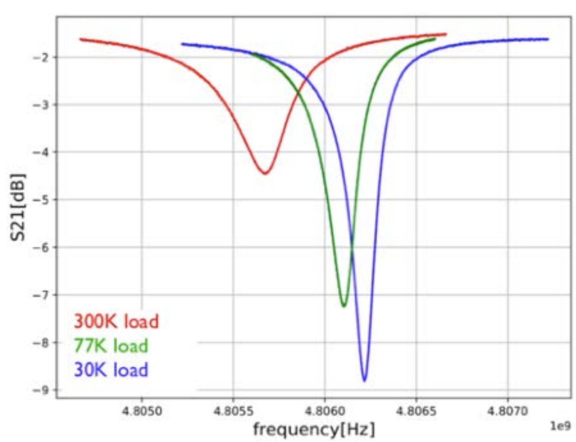


Optics design



NbTiN/Al-hybrid MKID: Lab measurements

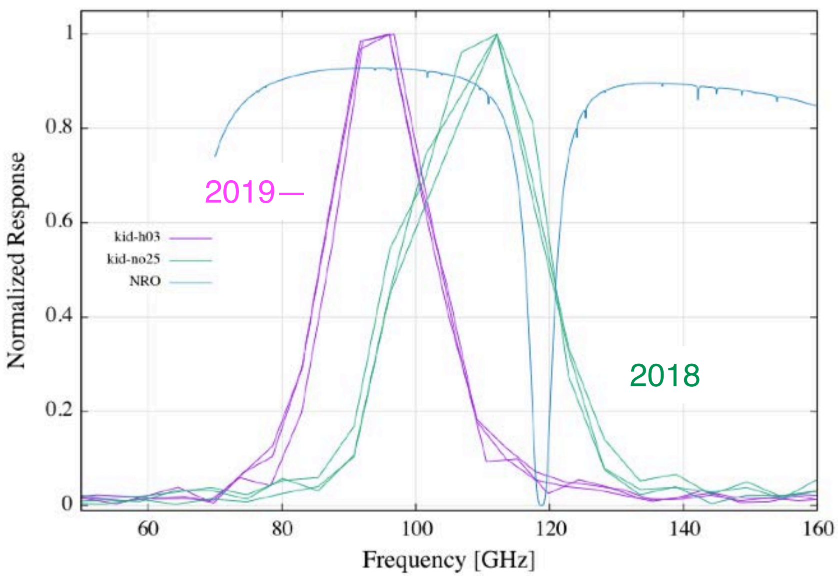




- Optical loads
  - Hot load (room temp.)
  - Cold load (liquid N_2, 77 K)
  - Mirror

→ Responsivity: ~1.5 kHz/K

NbTiN/Al-hybrid MKID: Lab measurements



Bandpass obtained w/ FTS (Hikawa20)

Figure of beam measurement

Beam position determined by knife-edge method

Advantage of hybrid MKID (Murayama21, in prep.)

Table for comparison

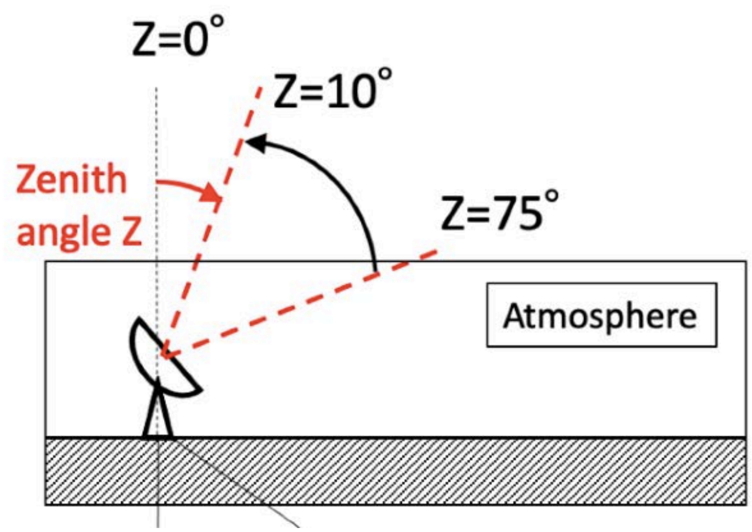
NEP result

Commissioning on NRO 45-m Radio Telescope

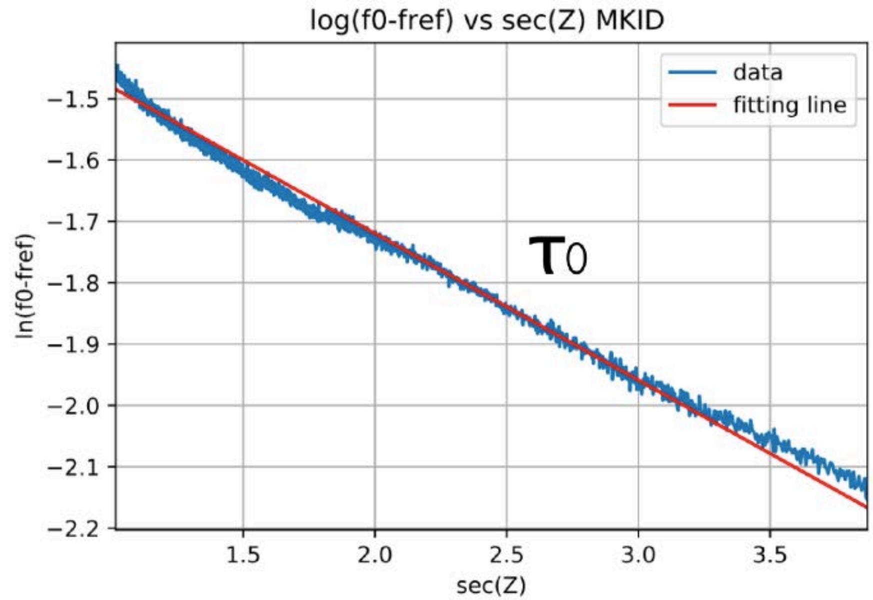
- 1st: Dec. 2016—Jan. 2017, Al MKID, 37 pixels
- 2nd: May—Jun. 2018, Al MKID, 108 pixels
- 3rd: May—Jun. 2021, NbTiH/Al-hybrid MKID, 108 pixels

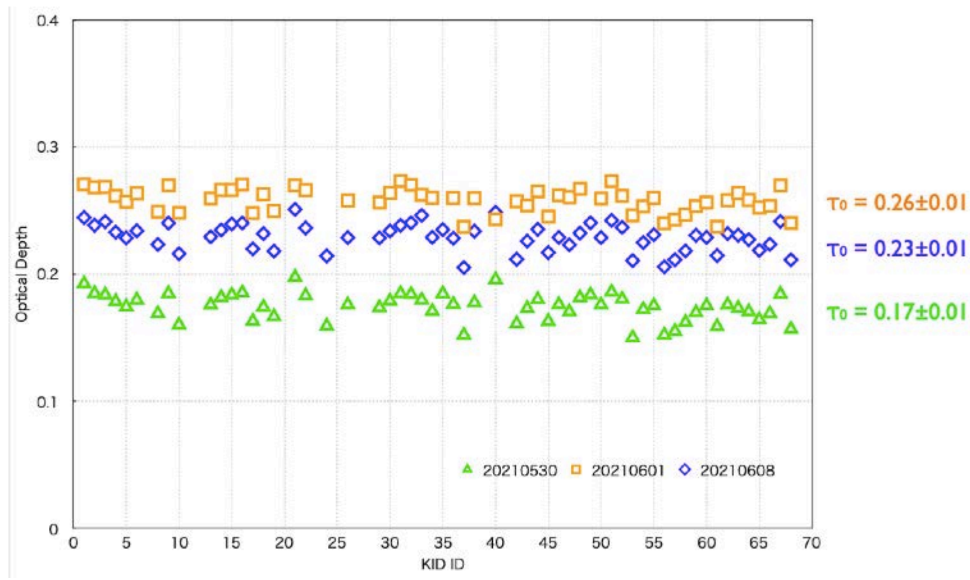



Measurement of Atmosphere (skydip)

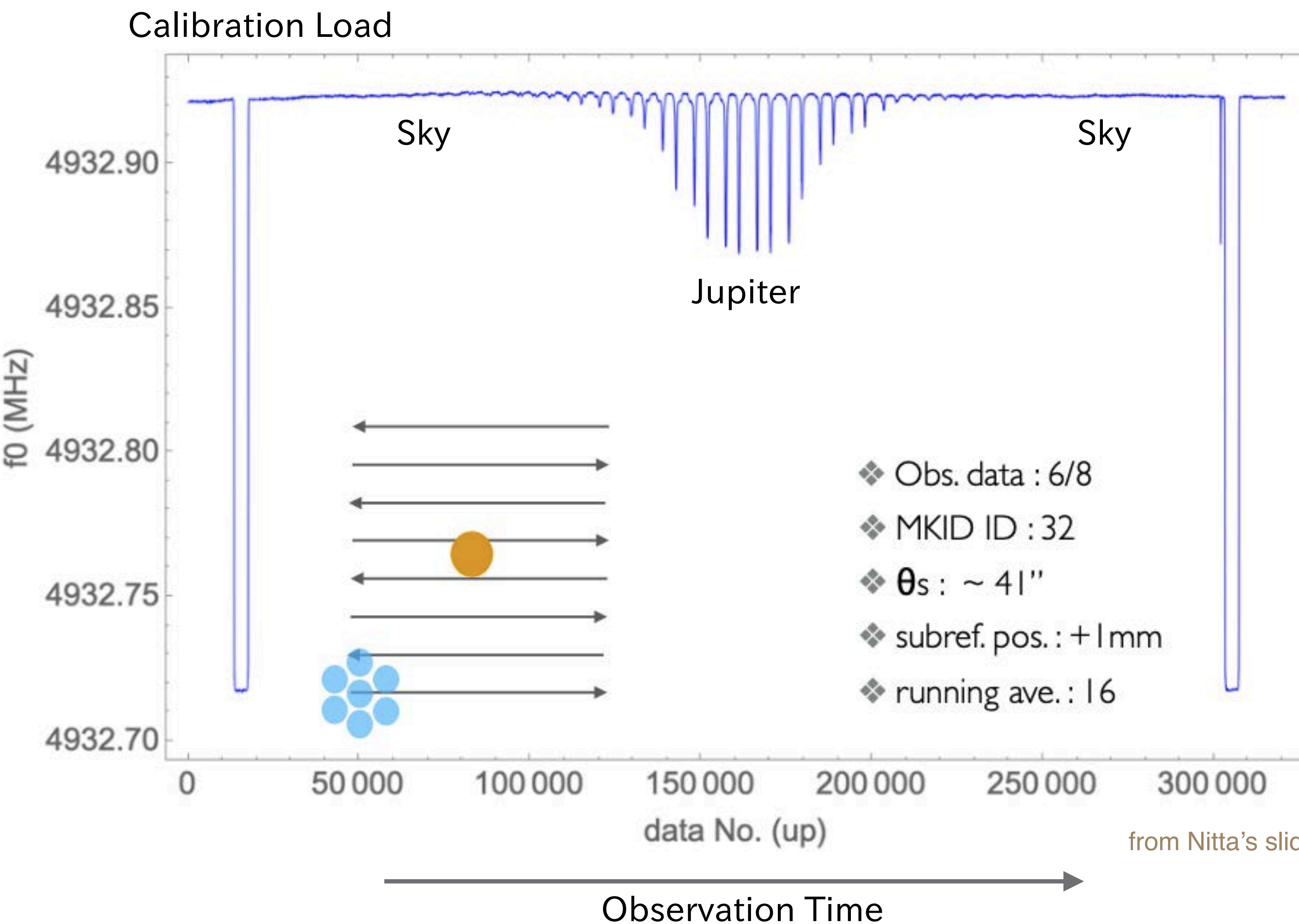


Hikawa18





Measurement of Planets



from Nitta's slide

Noise Equivalent Flux Density (NEFD) of a Pixel

NEP plot of commissioning 2018

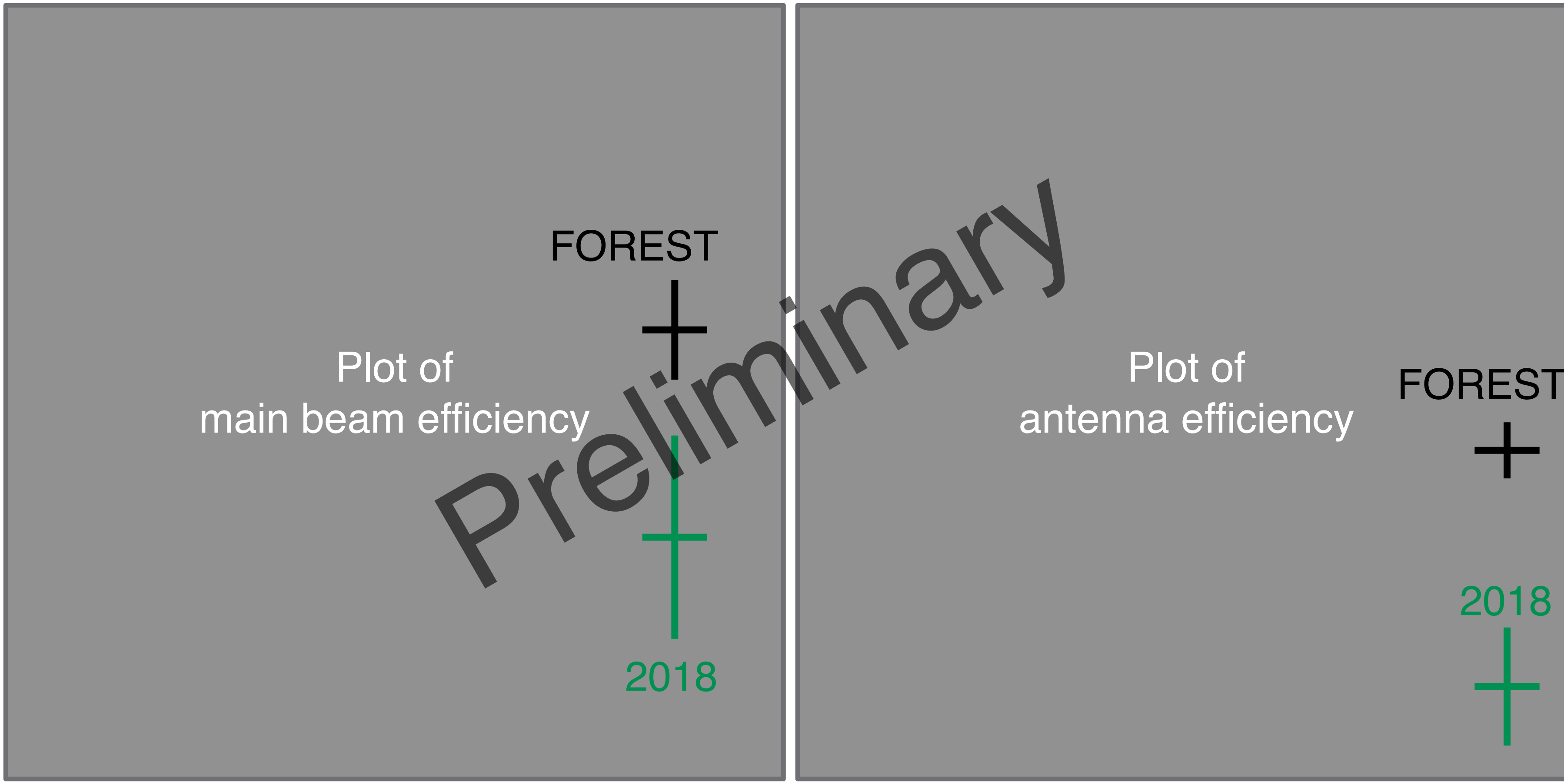
NEP plot of commissioning 2021

Preliminary

from Nitta's slide

- Sensitivity of each pixel improved by factor ~7

Efficiencies of Camera+Telescope



from Nitta's slide

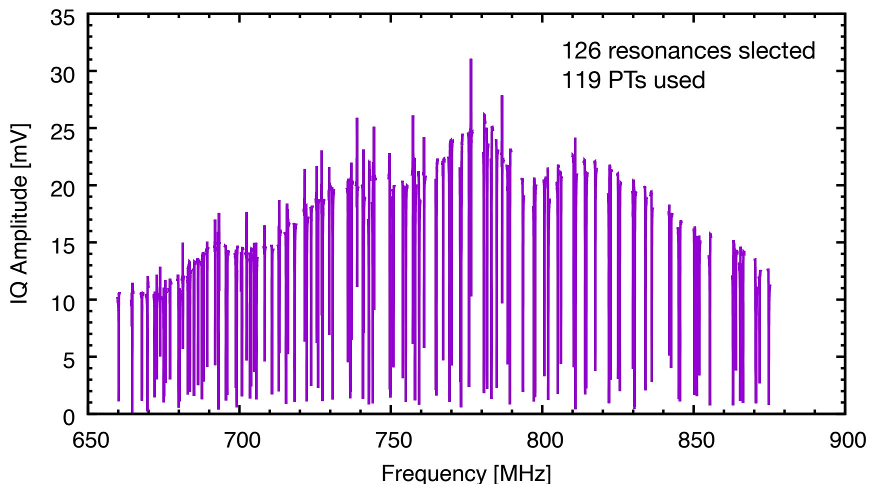
- Camera's coupling to the telescope became better, and is not much worse than other receivers on the telescope.

Current Summary of 3rd Commissioning

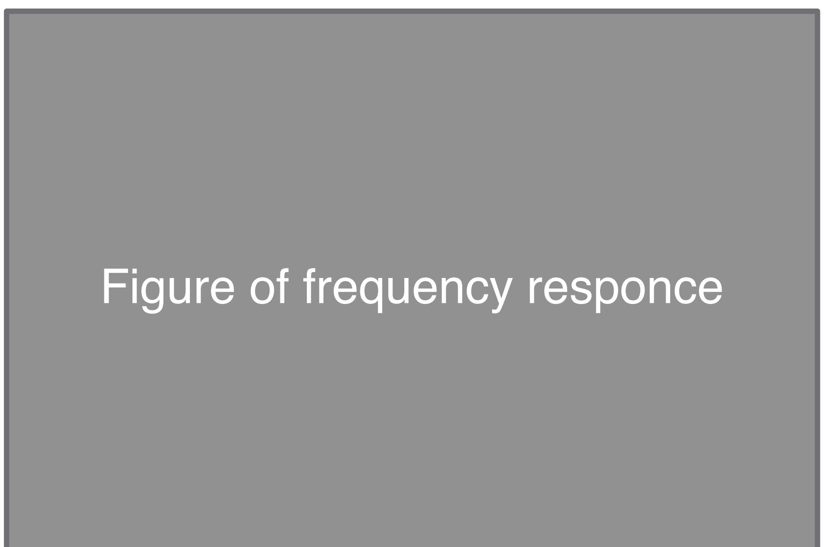
- The instrument works successfully.
- The sensitivity is improved as expected.
- The coupling btw camera & telescope became better.

- To do
  - Beam map, beam footprint
  - Map making
  - Map integration (map of diffuse source)

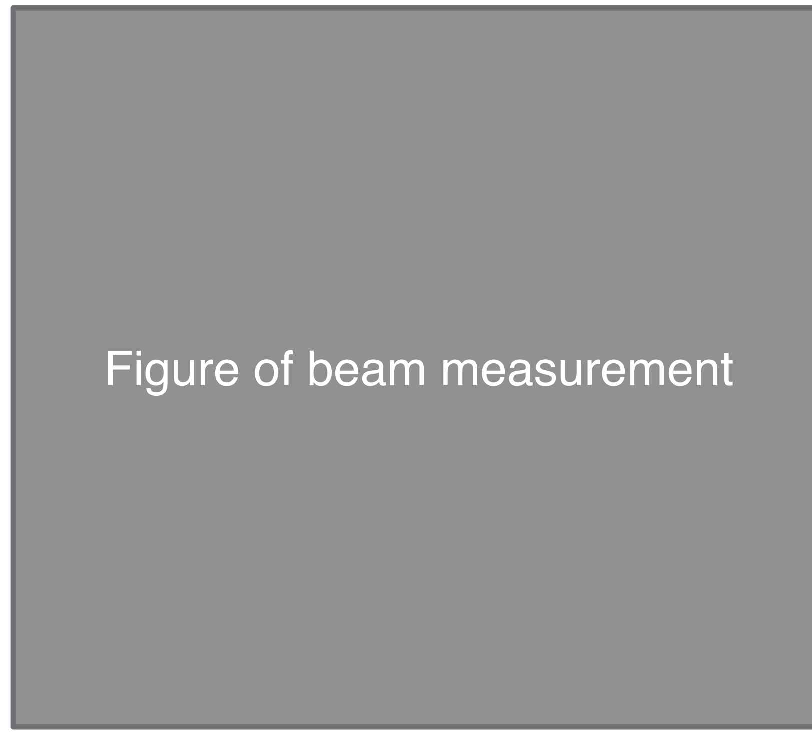
LEKID Array on Camera



Resonance spectra obtained w/ FSP (Nagai21)



Bandpass obtained w/ FTS



Beam position determined by knife-edge method

Conclusions

- The MKID camera had the 3rd commissioning in the last observation season.
- We'd like to confirm the camera sensitivity under the winter sky (optical depth ~0.1) in the next session.
- The MKID camera needs further improvement to achieve the photon noise limit on Nobeyama site.
  - MKID noise
  - Stray light
  - Readout efficiency
- Both technologies (antenna-coupled KID & LEKID) are important.
- We'd like to establish MKID camera operation in Japan, to open the way to next-generation radio telescopes.

Reference

1. Nagai et al., “Data Acquisition System of Nobeyama MKID Camera", Journal of Low Temperature Physics, Volume 193, Issue 3-4, pp. 585-592 (2018)
2. Nagai et al., “Resonance Spectra of Coplanar Waveguide MKIDs Obtained Using Frequency Sweeping Scheme", Journal of Low Temperature Physics, Volume 199, Issue 1-2, p.250-257 (2020)

- Acknowledgment

  KAKENHI (Kiban A: 26247019, Kiban C: 19K03920)

  LEKID arrays are provided by the NIKA2 team.