Development of millimeter-wave band MKID camera for wide-field continuum observations

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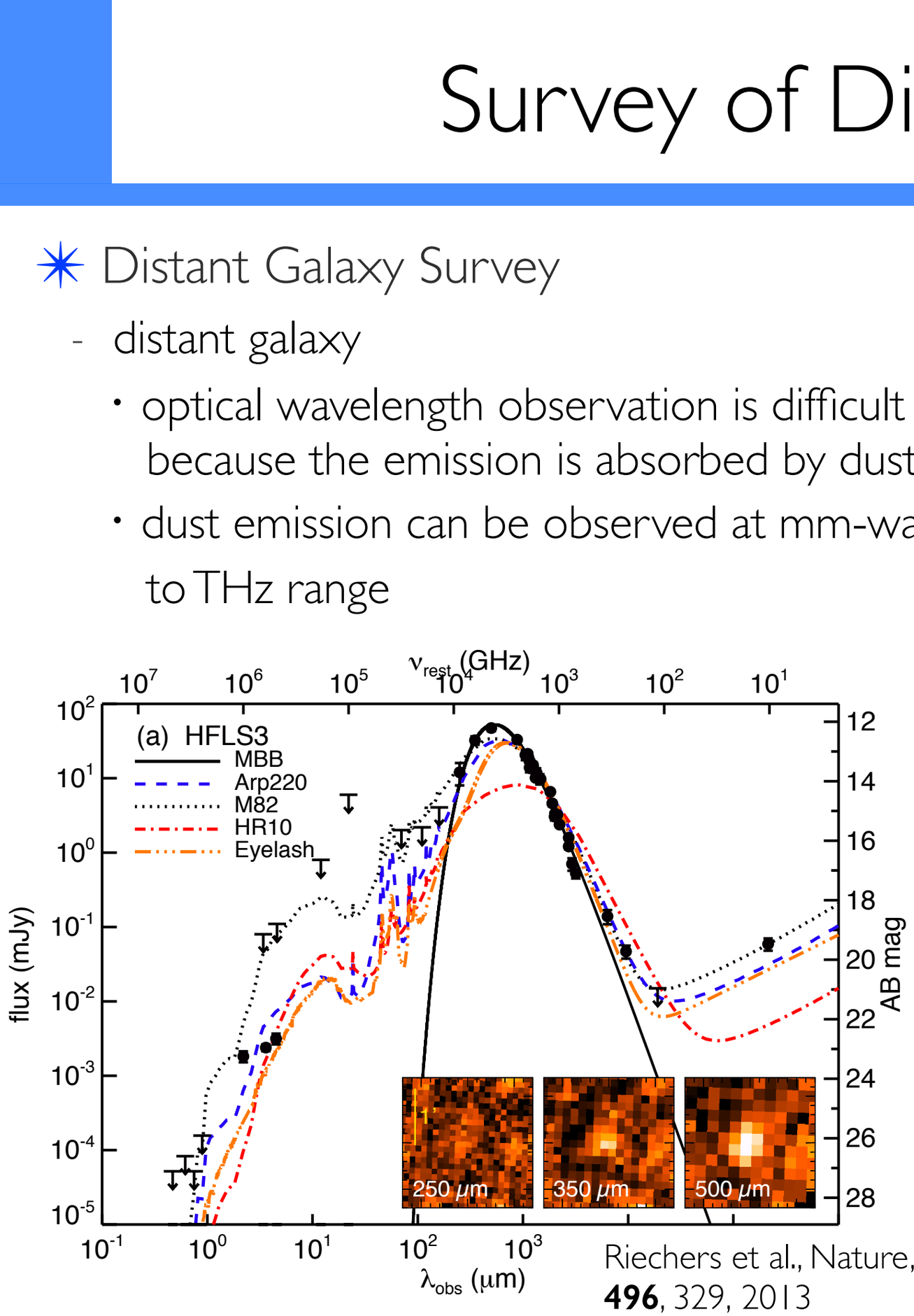
Survey of Distant Galaxies

✶ Distant Galaxy Survey

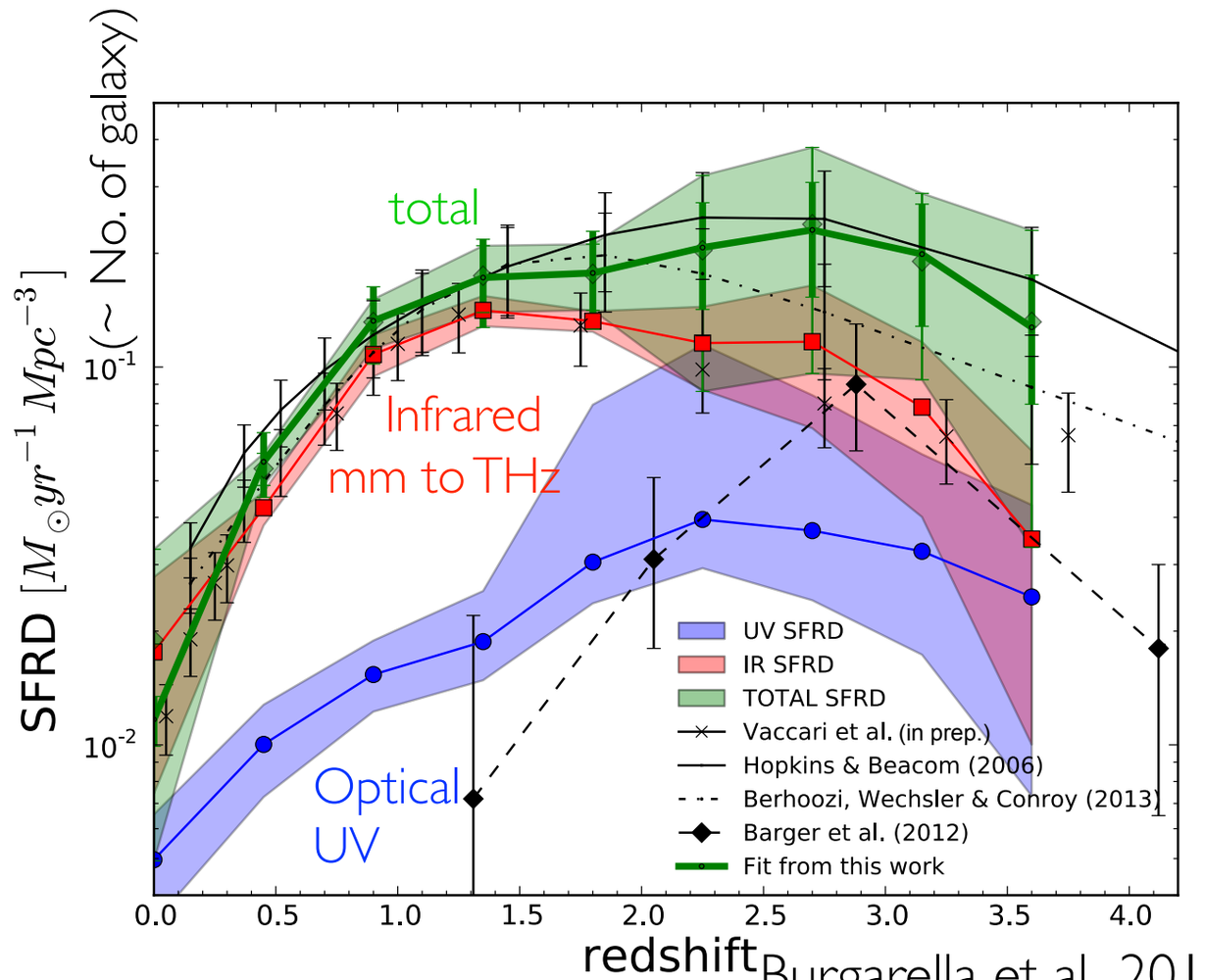
- distant galaxy
  - optical wavelength observation is difficult because the emission is absorbed by dust
  - dust emission can be observed at mm-wave to THz range



Riechers et al., Nature, **496**, 329, 2013

✶ Star Formation History

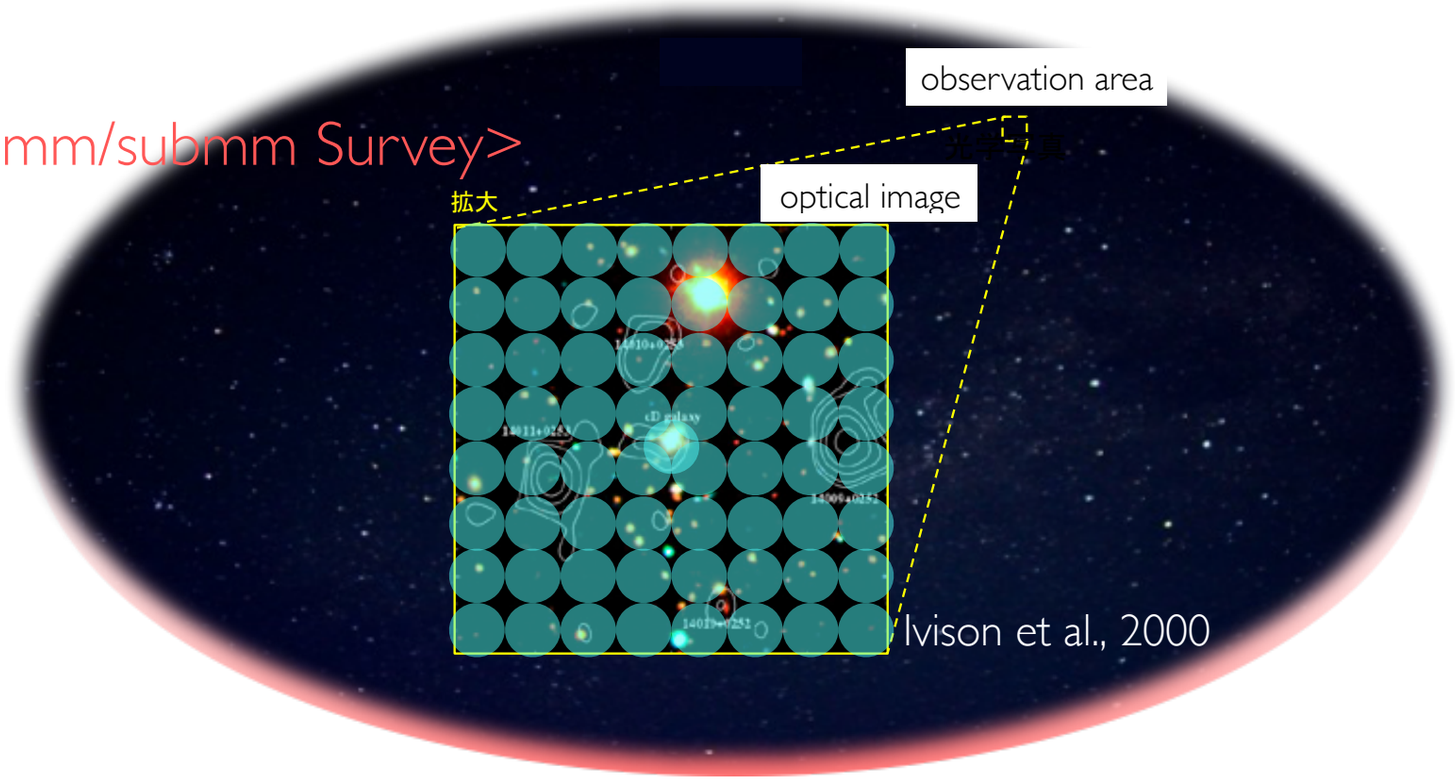
- redshift can be determined from the SED of the galaxy
- to reveal the star formation history at high-redshift, dust emission observation is important

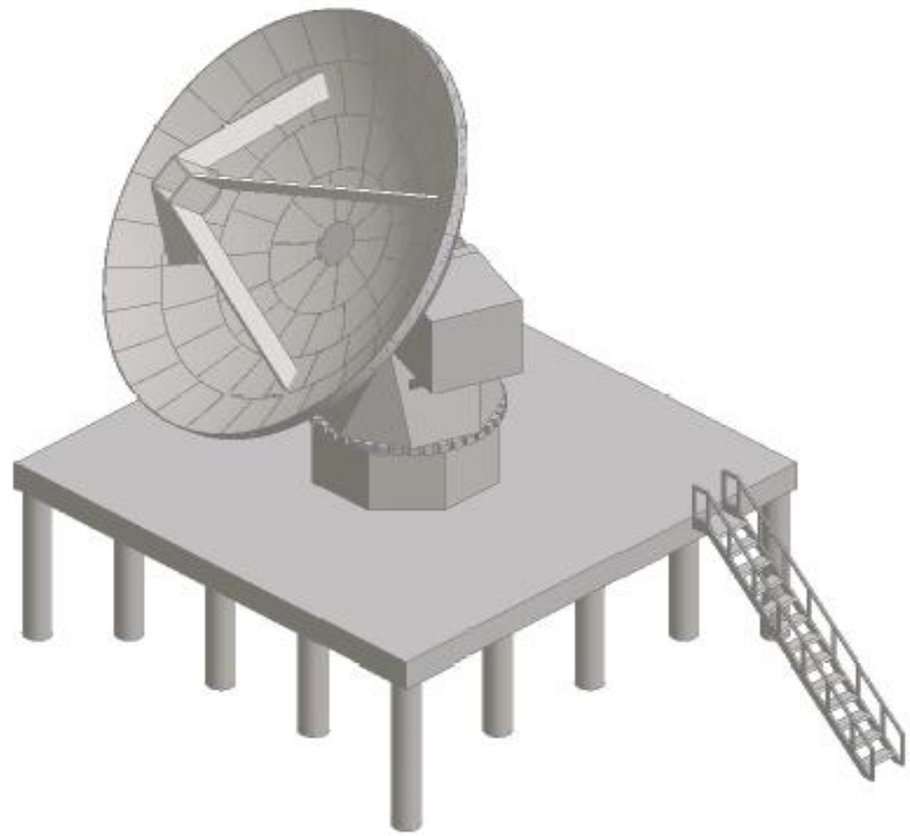


Burgarella et al., 2013

Wide-Field Observations

✳ Wide-field telescope and multi-pixel superconducting camera





ALMA : high-angular resolution interferometer
→ follow-up observations of galaxies detected by the camera

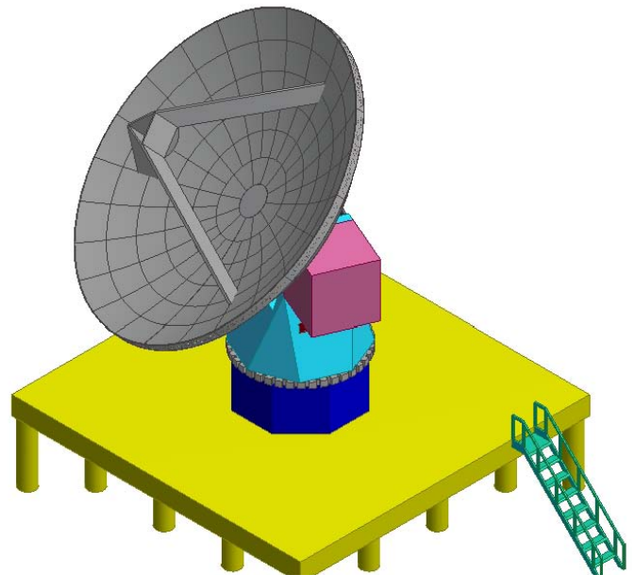
For distant galaxy survey,
- camera development for wide field-of-view observation
- good observation site for astronomical observations

are important

Wide-Field Continuum Camera

- 100-GHz band Camera (now developing)
  - Camera is installed to Nobeyama 45m telescope
  - Detector : 109 pixel MKID array
  - frequency band : 90 - 110 GHz
  - Field-of-view : ~ 3 arcmin

- THz band Camera (Future Plan)
  - Our group is planning to construct the 10 m telescope at the Antarctica plateau.
  - frequency band : 0.4 / 0.85 / 1.3 THz
  - Field-of-view : 1 degree



MKID detector is one of the important technology for realizing wide-field camera

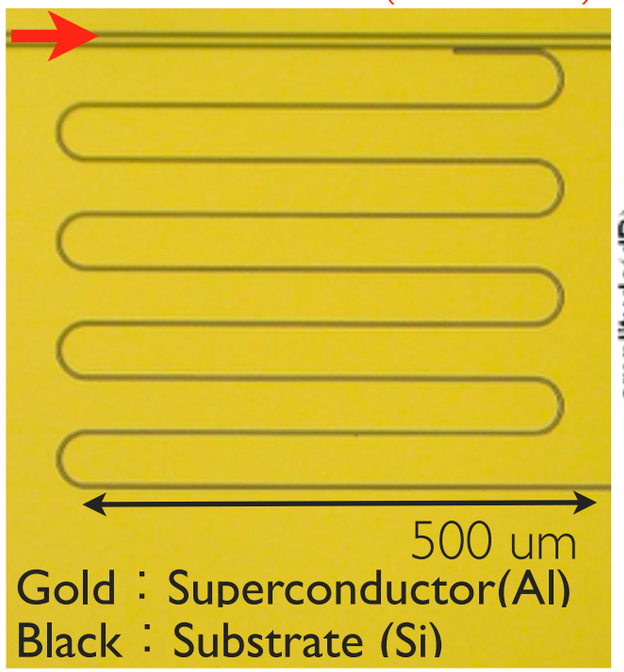
Microwave Kinetic Inductance Detector (MKID)

✳ Operation Principle

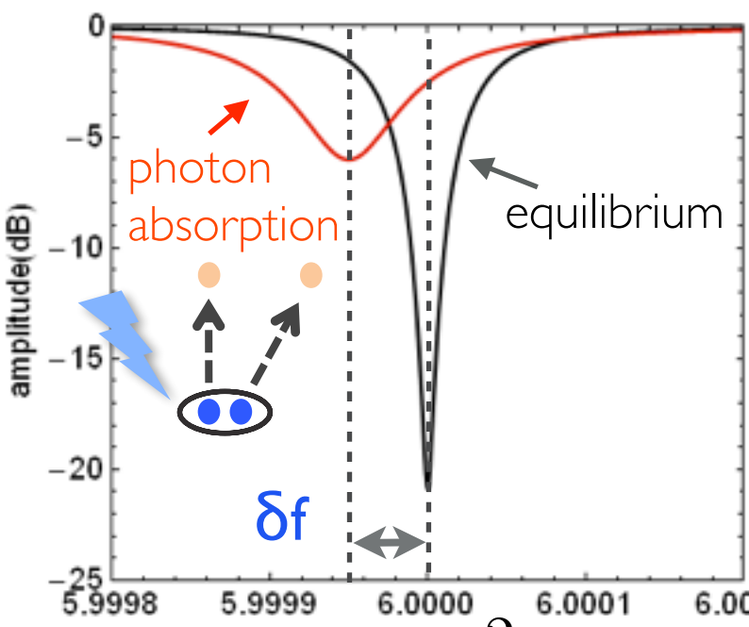
- Superconducting resonators operated in the microwave range
- Incident photons break Cooper-pair
  - → Kinetic Inductance is changed
  - → Resonance frequency of MKID is also changed

Signals from the objects are observed by monitoring the shift of the resonance frequency.

MW Readout (3 - 9GHz)



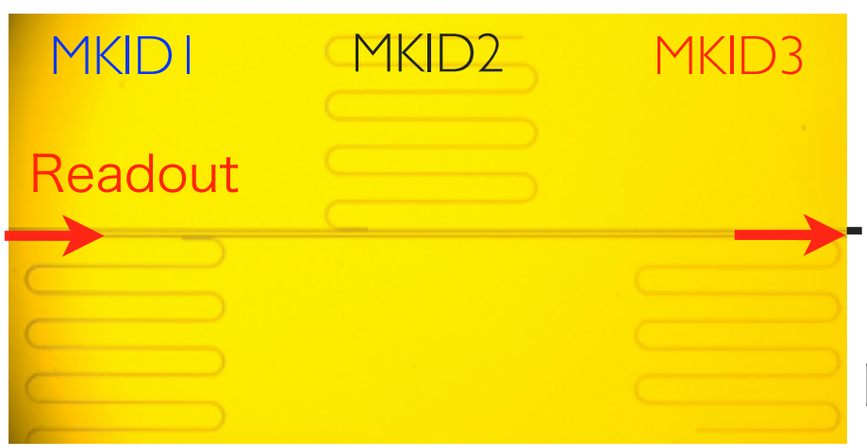
Day et al., Nature, 2003



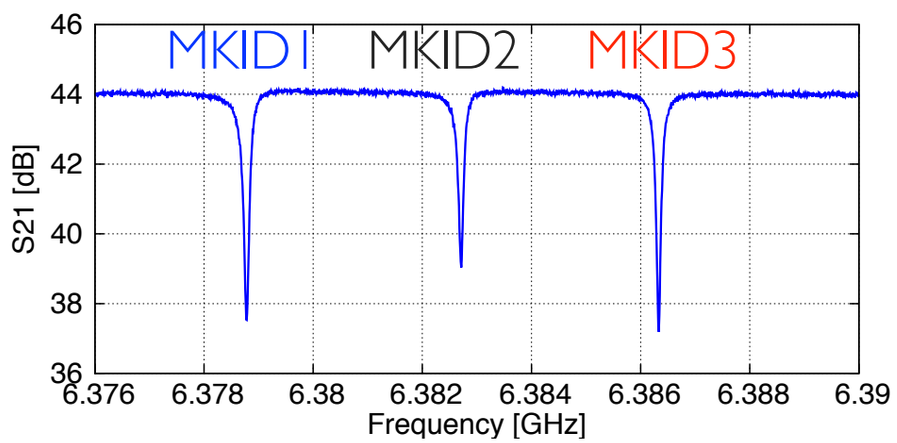
$$\omega_0 = \frac{2\pi}{4l\sqrt{(L_g + L_k)C}}$$

✳ Advantage of MKID

- High-detector yield is expected because the MKID fabrication process is relatively simple
- Intrinsic frequency multiplexing capability → ~1000 pixels can be measured with one LNA



Low-noise amplifier



MKID Camera for the Nobeyama 45m Telescope

✳ Millimeter-wave MKID Camera

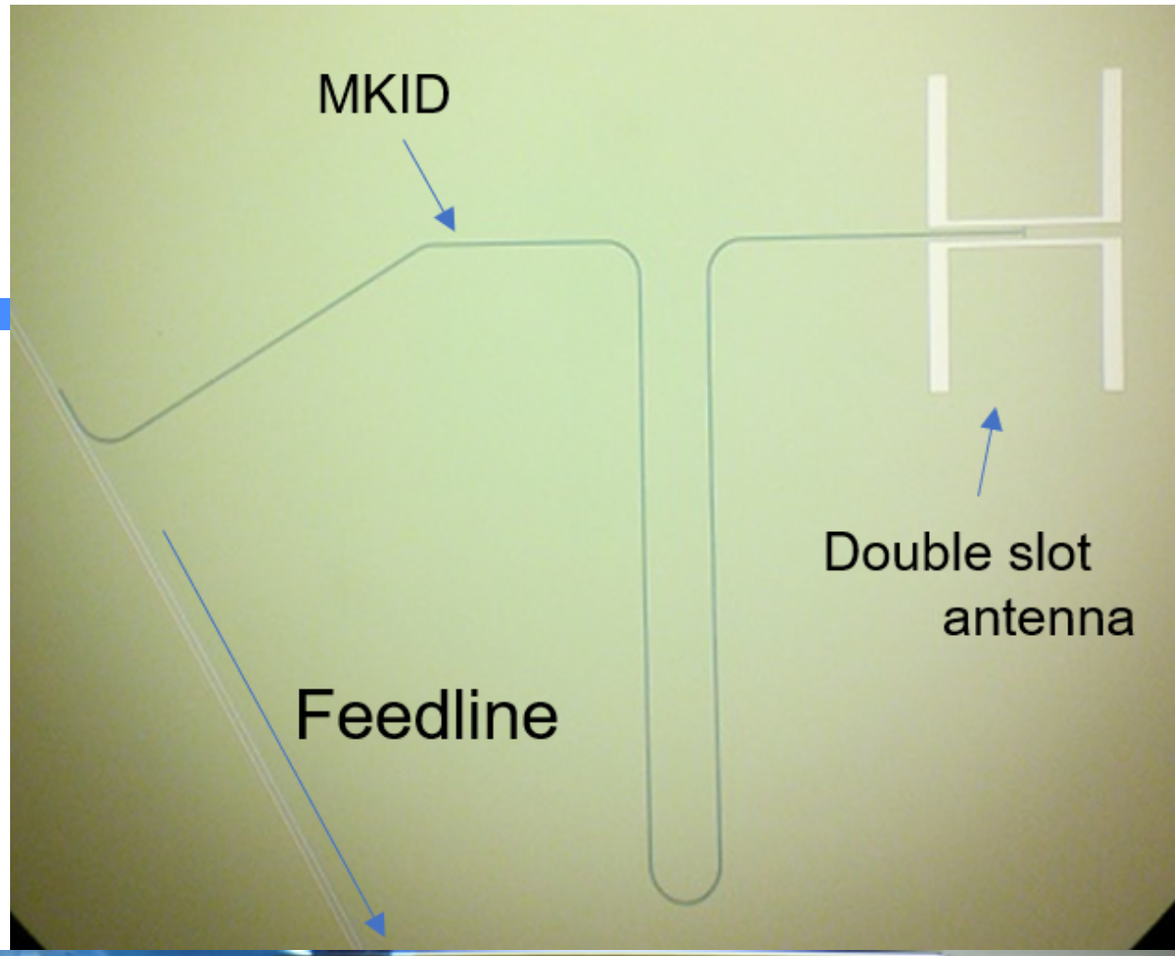
- Millimeter-wave MKID camera has been developed for the Nobeyama 45m telescope
- Collaboration with National Astronomical Observatory of Japan
- Optics of the 45 m telescope consists of the four reflective mirrors

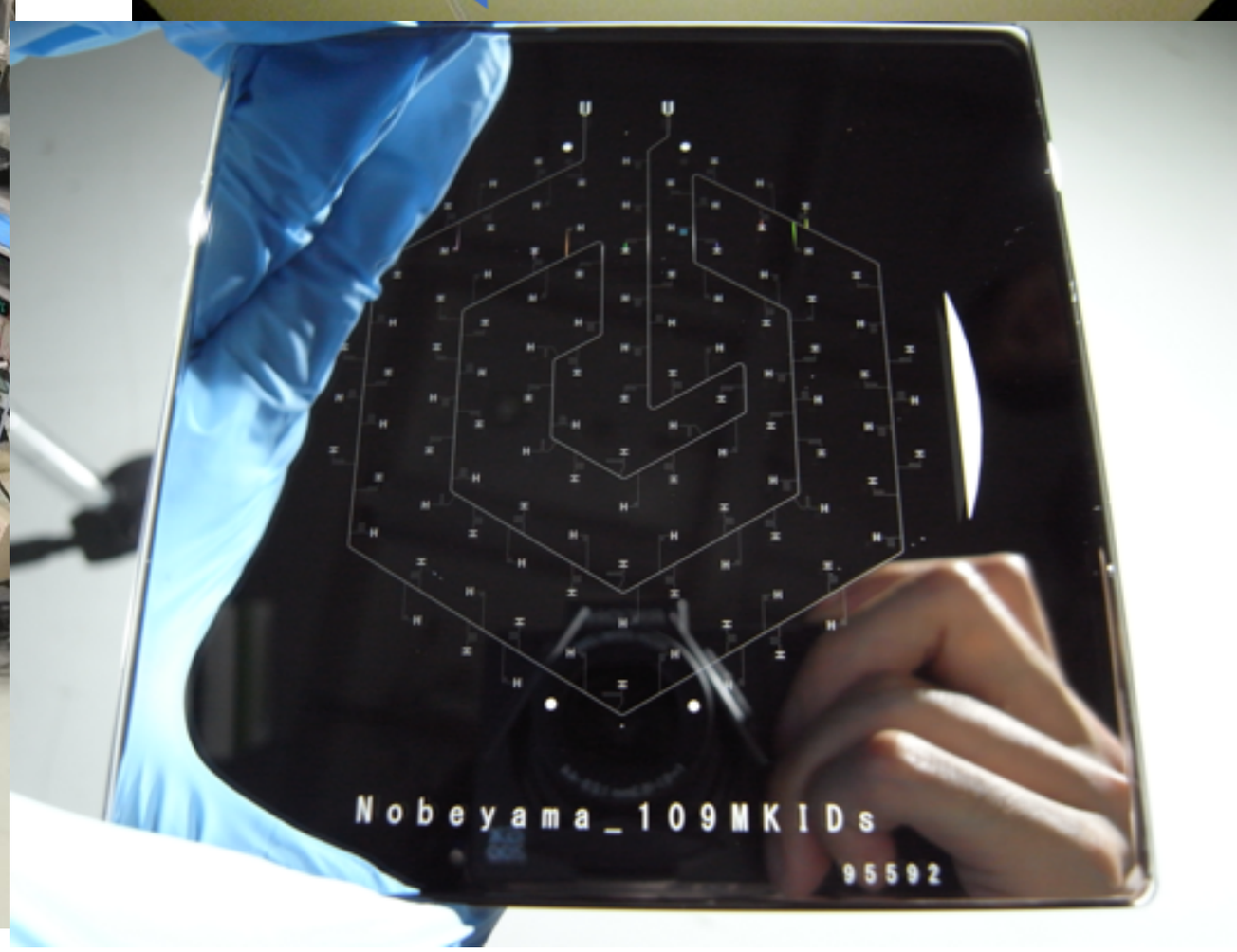
  → Two Si lenses are used to connect the telescope focus to the MKID array.

✳ Camera specifications

Observation Frequency	100-GHz band (90 – 110 GHz)
Field-of-view	~ 3 arcmin
Polarization	linear single polarization
Detector	Microwave Kinetic Inductance Detector
Cold Optics	Refractive optics using Si lens
No. of pixels	109 pixels
Bath temperature	< 200 mK

Cryostat Design

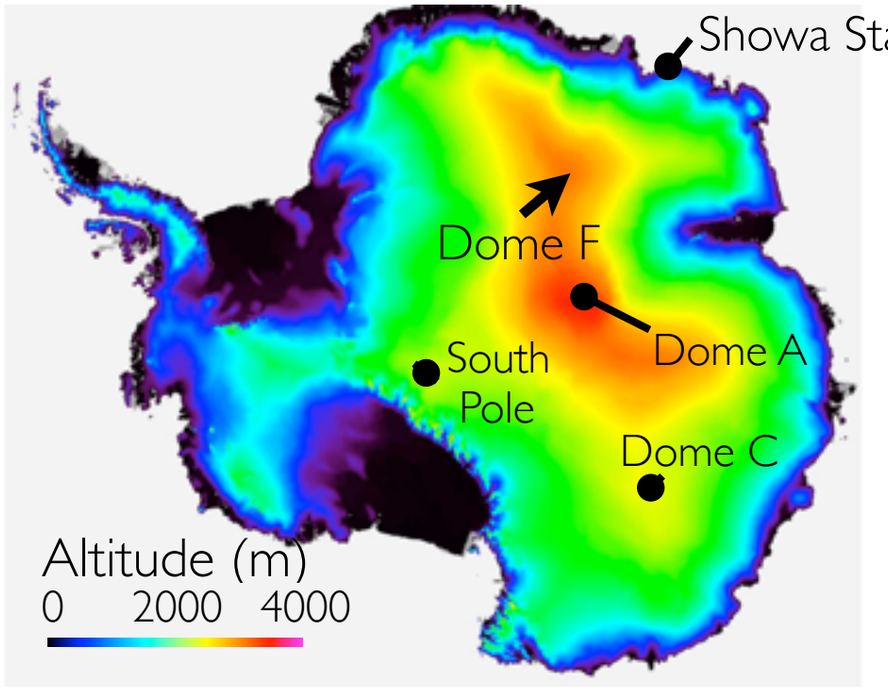




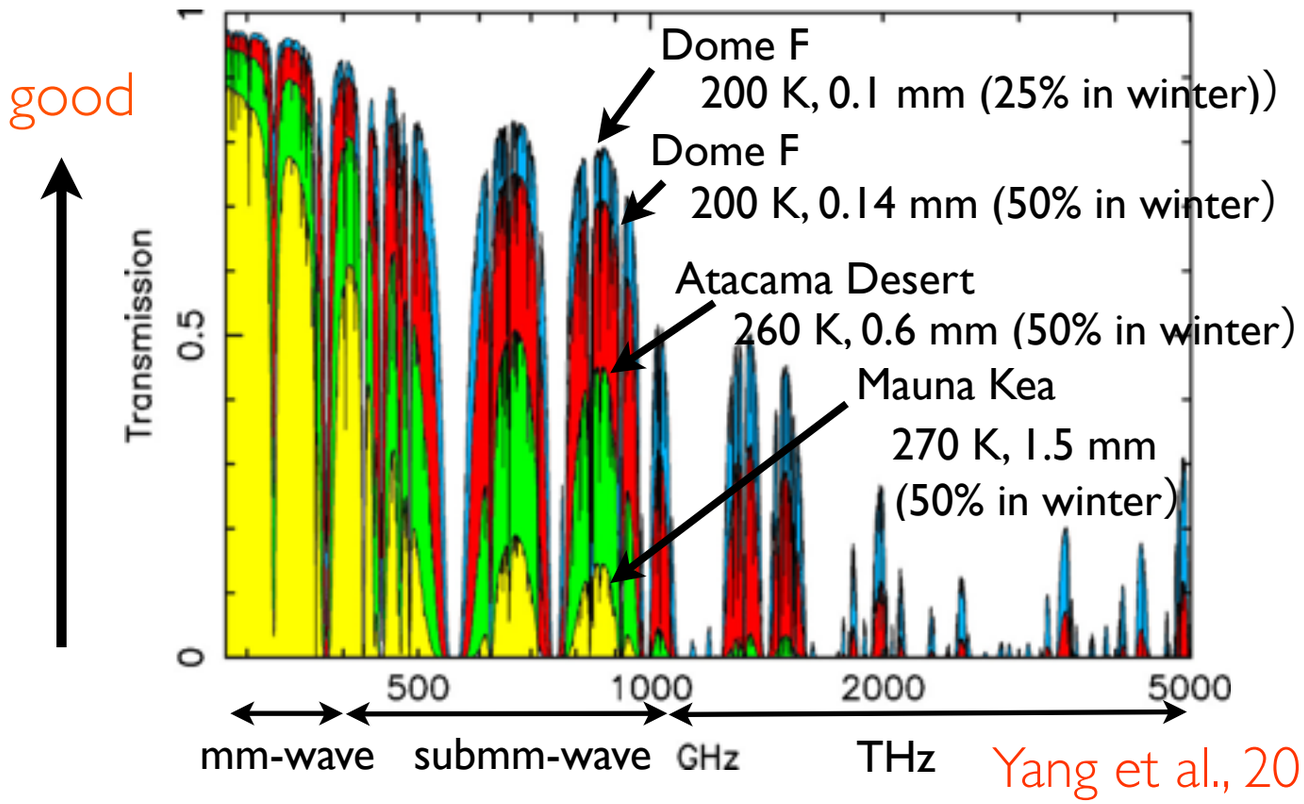
Antarctica Plateau

✶ Planning telescope at Antarctica

- 10 m class telescope @ Dome C (France-Italy site)
- 30 m class telescope @ New Dome F (Japanese site)



✶ Comparison to other sites



Yang et al., 2010

< e.g. Atacama / Mauna Kea >

- very good site for astronomy
- There are a lot of telescope on these sites

< Antarctica >

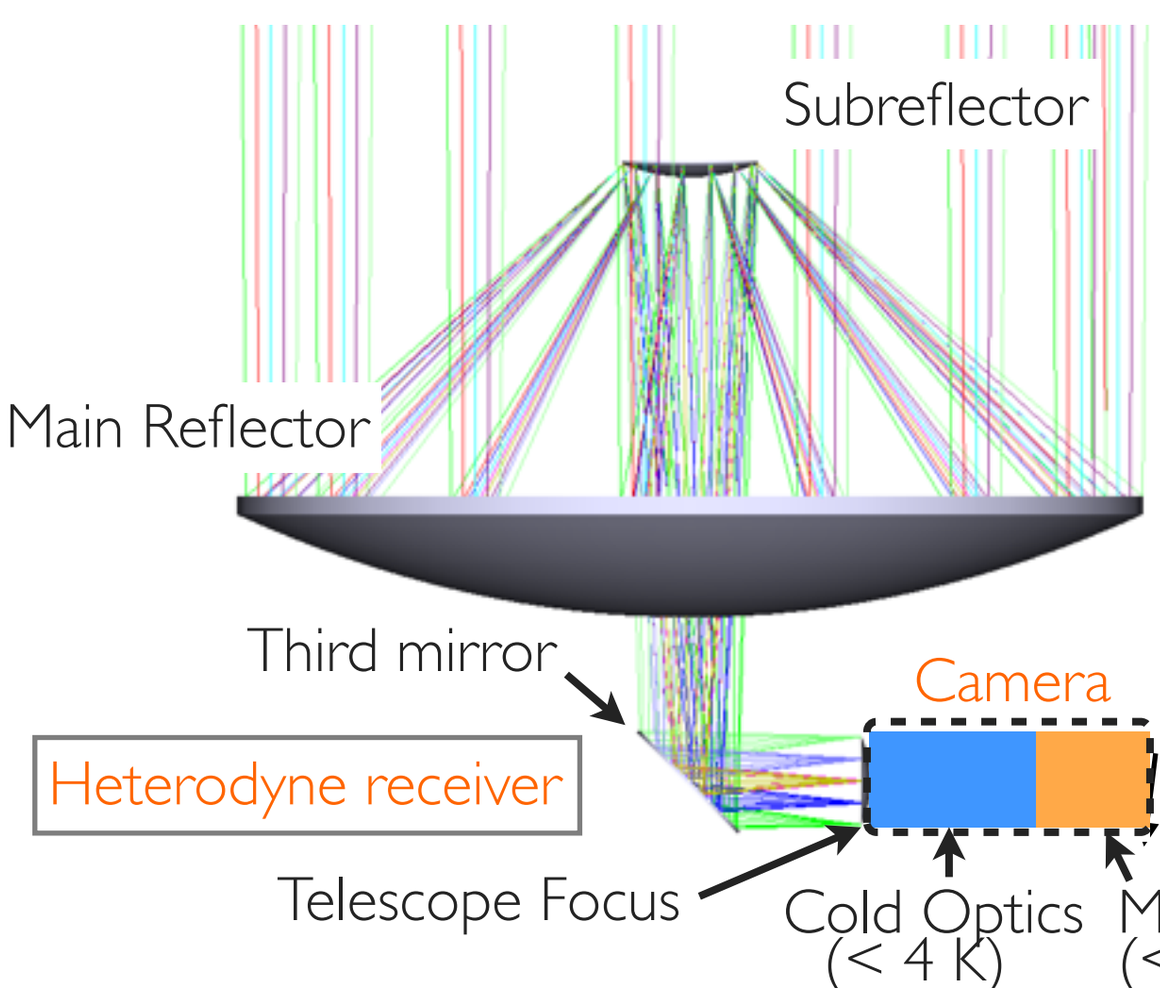
- higher transmittance
- THz bands are only available at the Antarctica

Antarctica is the best site for millimeter-wave and terahertz astronomical observations

MKID Camera for Antarctica telescope

✳ Antarctic 10 m Telescope

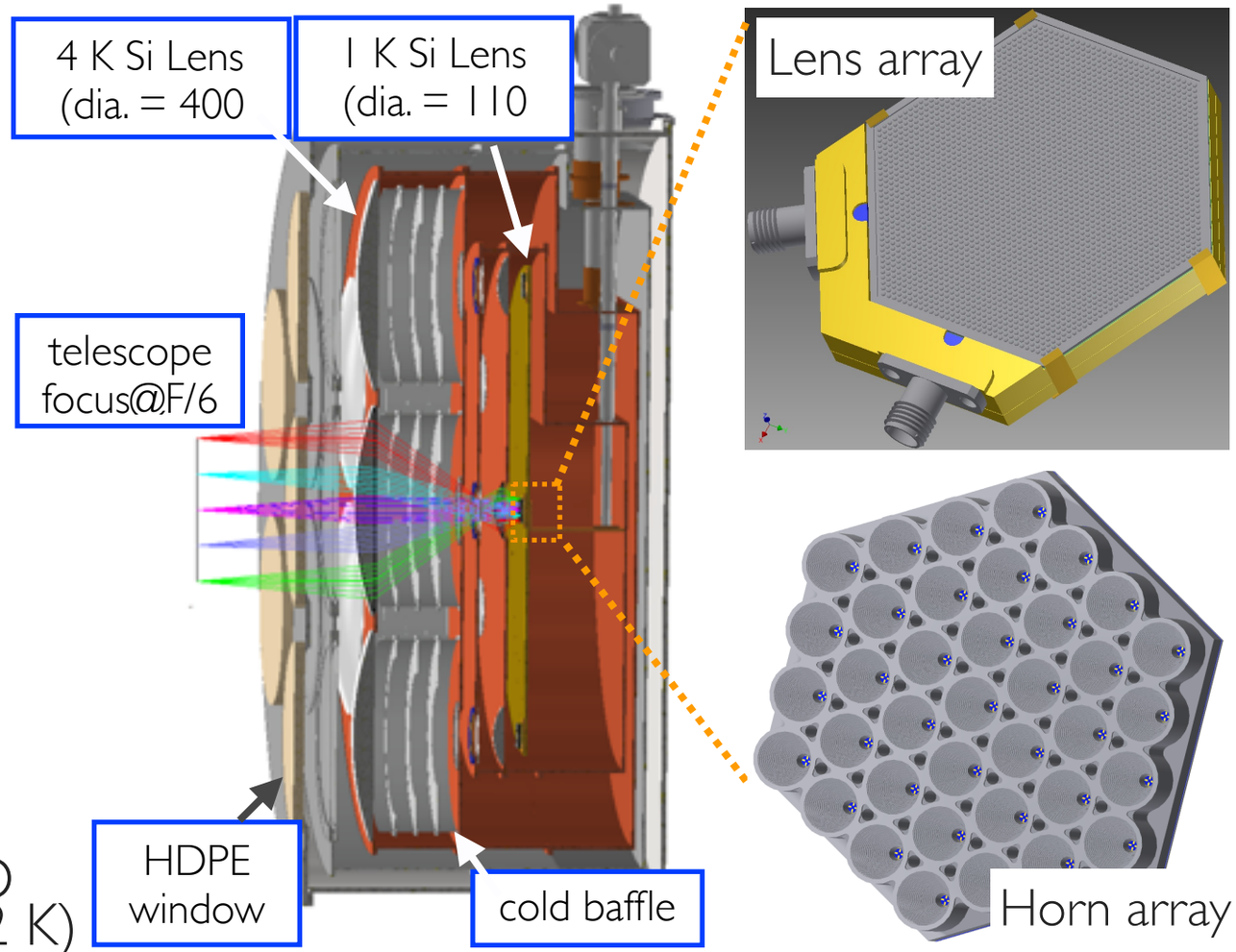
- Field-of-View：1 degree
  - Survey of distant galaxy
- Two instruments @ Nasmyth focus
  - Heterodyne receiver & Camera
  - Select by changing the third mirror



✳ THz band MKID Camera

- 7 optics tubes with Si lens
  - based on the NRO 45m MKID camera
  - ~20000 pixels for 0.45, 0.85, 1.3 THz
- Two types of focal plane arrays

  →Si lens array and horn array



Summary

✴ Scientific Motivation

- distant galaxy survey
  - wide-field survey is important to detect the unknown galaxies
  - redshift can be determined from the spectrum energy distribution

✴ MKID camera development

- MKID camera for the Nobeyama 45 m telescope
  - 109 pixel array using lens-antenna coupled MKID
  - dark NEP : ~ 10^{-16} [W/rHz]
    - improvement of the sensitivity is needed
  - Beam pattern measured with planets is comparable with the simulation

✴ Future development

- Antarctica is the best site for THz astronomy
- ~ 20000 pixel camera is designed for the Antarctic 10 m telescope