# Progress toward Antarctic Terahertz Intensity Interferometry

Hiroshi Matsuo*[1], Hajime Ezawa[1], Ayako Niwa[2], Tomohiro Koseki[2], Rina Enohi[3], Norio Okada[1]
and Antarctic Terahertz Astronomy Group in Japan

***Abstract*— Terahertz Intensity Interferometry can be a technology for future high angular resolution and high sensitivity observations in far-infrared and terahertz frequencies. Optical demonstration with a laboratory interferometer is being prepared using submillimeter-wave SIS photon detectors, cryogenic readout electronics, 0.8-K sorption cooler and a 4-K cryostat with a pulse tube cooler. Some of the design details of the setups are presented. Using the technology, Antarctic intensity interferometer with two 30-cm terahertz telescopes at Dome Fuji station is proposed using 500 GHz SIS mixers and 1.5 THz SIS photon detectors.**

***Keywords*— *intensity interferometer, SIS photon detector, cryogenic readout electronics, sorption cooler***

## I. Introduction

Astronomical observations of atomic fine-structure lines in far-infrared and terahertz frequencies, such as [OIII], [NII] and [CII], have advanced by observing high redshift galaxies with ALMA to identify redshifted emission lines observable in millimeter and submillimeter-waves. However, observing rest-frequencies of these emission lines is difficult owing to atmospheric absorption. From high altitude sites in Antarctica, Dome Fuji and Dome A, some of the far-infrared emission lines can be observed. We are proposing Antarctic terahertz interferometers to observe such emission lines with high angular resolution. Intensity interferometry is a possible technology applicable to the terahertz interferometer for aperture synthesis imaging by utilizing photon bunches for delay time measurements [1-3].

## II. Preparation of Lab. Experiments

The key technology for aperture synthesis imaging with intensity interferometry is to measure intensity correlation with large bandwidth and high sensitivity. SIS photon detectors are developed for 500-660 GHz which could be used for photon counting experiments. Details of the detector development are presented in Ezawa et al. [4]. To observe [NII] emission line, SIS photon detectors at 1.5 THz is being developed in Advanced Technology Center of National Astronomical Observatory of Japan, which is presented in Niwa et al. in this symposium.

Fig. 1 shows a setup inside a cryostat. On a 4-K stage (30 cm × 20 cm), a 0.8-K stage supported by CFRP plates is cooled by a compact 0.8-K sorption cooler. An SIS photon detector on hyper-hemispherical silicon lens is attached to the 0.8-K stage and DC magnetic field is applied by a pair of superconducting magnets at 4 K to suppress Josephson currents. The magnets and the detector are covered by a magnetic shield made of cryophy (not shown in Fig. 1) to avoid magnetic traps on SIS junctions. Another SIS photon detector can be attached to the other side of 0.8-K stage for interferometer experiments.

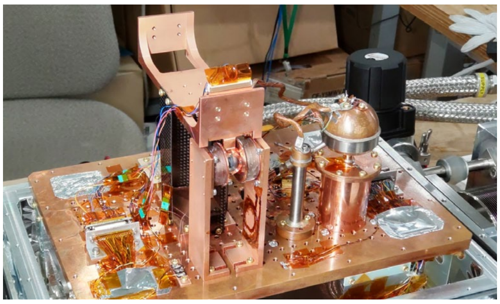

Fig. 1. A setup for cooling SIS photon detectors with 0.8-K sorption cooler on 4-K stage in a cryostat.

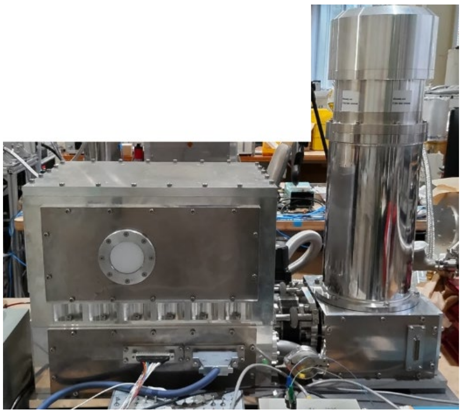

Fig. 2. A cryostat with a pulse-tube cooler for demonstration of terahertz intensity interferometry. There are two optical windows, one in front and another at the oposite side.

The cryostat shown in Fig. 2 is cooled by Sumitomo pulse-tube cooler RP-062BS. Thermal link from the cold head to 4-K and 60-K stage is made by 6N copper cables to suppress mechanical vibration. Two optical windows are made of UHMW polyethylene with anti-reflection coating of Zytex. Black polypropylene and Yoshinaga-filters are used on 60-K and 4-K windows, which are anti-reflection coated with Zytex and Teflon, respectively.

## III. Cryogenic Readout Electronics

Schematic diagram of a readout electronics is shown in Fig. 3. To realize fast readout of high impedance detector, a first stage source follower with GaAs-JFET is used aside of the SIS photon detector at 0.8 K. Power dissipation of the first stage is less than 100 μW and output impedance of a few kΩ is measured. Then a second stage source follower with GaAs-HEMT at 4-K lowers the output impedance down to 50 Ω, followed by a Si:Ge amplifier (CITLF1). Readout noise is limited by the first stage source follower with transconductance of 0.3 mS with thermal limited noise voltage of about 0.4 nV/Hz$^{0.5}$ and noise temperature of about

[1]National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan; [2]University of Tsukuba, Tsukuba, Ibaraki 305-8577, Japan; [3]Toho University, Funabashi, Chiba 274-8510, Japan

60 K. Bandwidth of the readout electronics is less than 1 GHz limited by output impedance of the first-stage source-follower and the second stage gate capacitance. The noise and bandwidth could be improved by using low gate leakage HEMT transistors instead of GaAs-JFET.

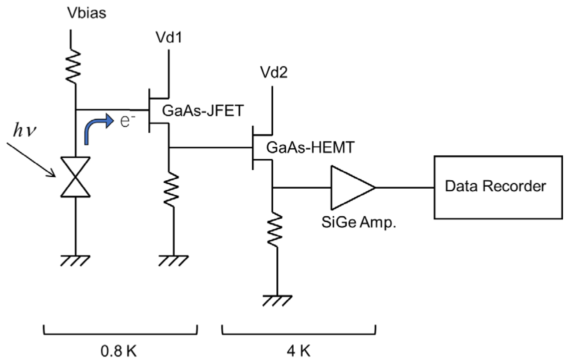


Fig. 3. Schematic diagram of the cryogenic readout electronics for SIS photon detectors, using dual-stage source-followers and a Si:Ge amplifier.

## IV. Optical Setup of Interferometer Experiment

Fig.4 shows a picture of optical setups for intensity interferometry. Optical mirror assembly and off-axis parabolic mirror focus input radiation to SIS photon detectors inside the cryostat. Using a high temperature blackbody source and ϕ600-mm spherical mirror, radiation from astronomical source is simulated. Input radiation is then reflected by two input mirrors on movable stages to obtain baseline separation between 10 and 50 cm. Rotation of the baseline can be simulated by rotating a shaped aperture in front of the blackbody. Input radiation is focused by off-axis parabolic mirror in front of each window as in Fig.2. Inside each cryostat window, an SIS photon detector on silicon lens measures photo current which is readout by cryogenic readout circuits. Signals from two SIS photon detectors are recorded simultaneously by a wide bandwidth oscilloscope for further analysis of intensity correlation. Data will be collected for different baseline configuration and shaped aperture rotation to obtain intensity correlation and delay time, which will be used to make aperture synthesis imaging.

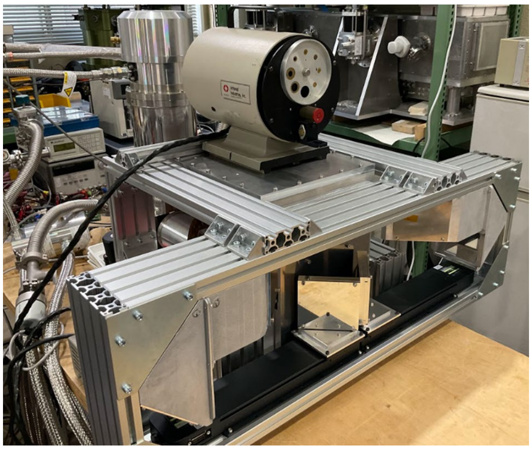

Fig. 4. An optical setup for laboratory demonstration of intensity interferometry. A ϕ600 mm spherical mirror (R=4800 mm) out of the picture is used to collimate radiation from the blackbody (on a cryostat) to two input mirrors on moving stages. Separation of the input mirror can be changed between 10 and 50 cm.

## V. Toward Antarctic Intensity Interferometry

Antarctic observation from Dome-Fuji is supported by National Institute of Polar Research (NIPR). Dome-Fuji astronomy program with 30-cm terahertz telescopes is starting by a general research observation of the 10th term Japanese Antarctic research program. In Early 2025 by the 66th Japanese Antarctic Research Expedition (JARE-66), the first 30-cm telescope will be installed in Dome-Fuji to start observation of Galactic plane survey of CO and CI emission lines using 500-GHz SIS mixer receivers. Experiment on terahertz intensity interferometry is planned with another 30-cm telescope with similar design.

A schematic presentation of the Antarctic Terahertz Intensity Interferometer is shown in Fig. 5. Two 30-cm telescopes with SIS mixers and/or SIS photon detectors will be used to record intensity fluctuation caused by photon bunches from astronomical sources.

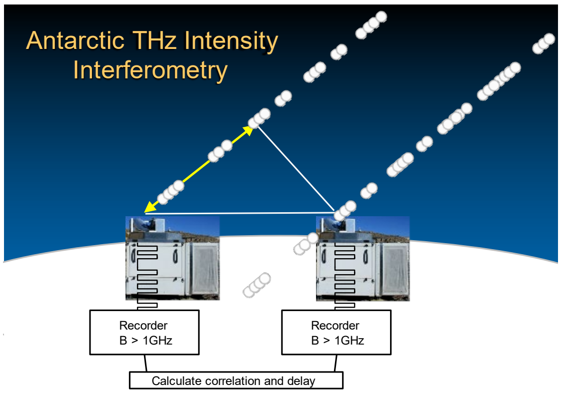


Fig. 5. A concept of Antarctic Terahertz Intensity Interferometer.

The second 30-cm telescope is proposed to be installed in Dome-Fuji station in early 2027 to start test observation of intensity interferometry using 500 GHz SIS mixers. During the 10th term Antarctic program until 2028, baseline separation would be limited to 10's of meters in Dome-Fuji station. We will then install 1.5-THz SIS photon detectors to observe [NII] 1.46 GHz emission lines toward massive star-forming regions in our Galaxy and external galaxies.

## Acknowledgments

This development is supported by JSPS KAKENHI Grant Number 20K20346, 20K20345 and JAXA basic R&D for future space science missions.

## References

[1] Matsuo, H., Ezawa, H., "Advantages of Photon Counting Detectors for Terahertz Astronomy", Journal of Low Temperature Physics 184, 718, 2016

[2] Matsuo, H., "Far-infrared intensity interferometry for high angular resolution imaging", Proc. SPIE 11443, 114431N, 2020

[3] Matsuo, H., "Development of Terahertz Intensity Interferometry for Very High Angular Resolution Observations", Impact 2020(5), pp. 39-41, 2020

[4] Ezawa, H., Matsuo, H., Ukibe, M., Fujii, G., Shiki, S., "Optical Performance of SIS Photon Detectors at Terahertz Frequencies", JLTP 200, pp. 226-232, 2020