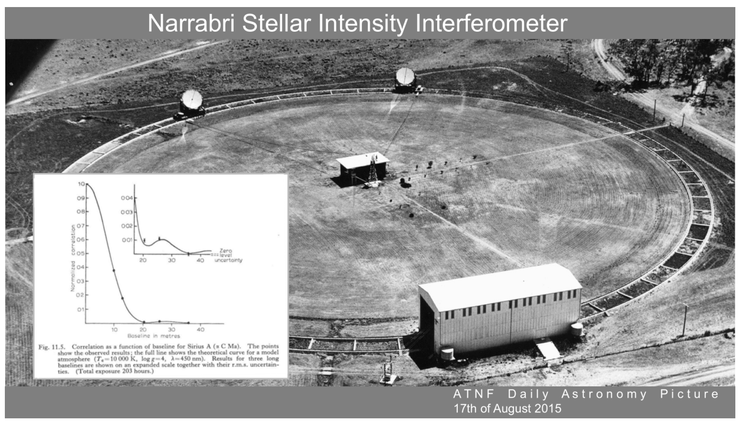
Elucidating formation and evolution of celestial bodies using far-infrared and terahertz interferometers

Hiroshi Matsuo, Hajime Ezawa, Tai Oshima, Takeshi Kamazaki, Takehiko Wada (NAOJ), Nario Kuno, Shunsuke Honda, Takuya Hashimoto, Tomohiro Koseki (U Tsukuba), Masumichi Seta, Naomasa Nakai (Kwansei Gakuin U), Takashi Kamizuka (U Tokyo), Hanae Inami (Hiroshima U), Tohru Nagao (Ehime U), Kiwamu Izumi, Takao Nakagawa (JAXA), Taro Matsuo (Nagoya U)

Science Goals of FIR/THz Interferometry

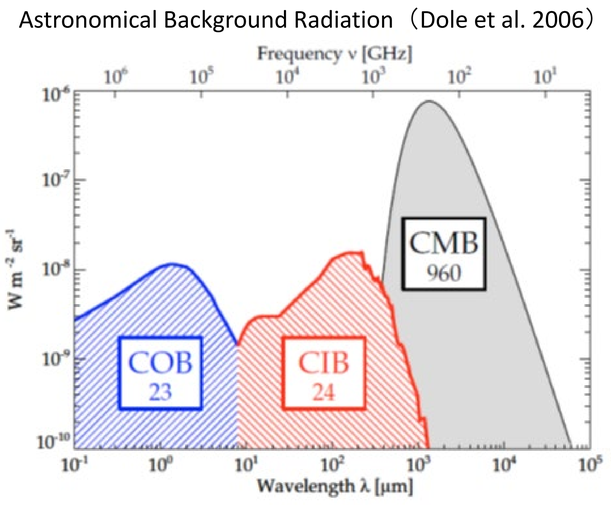
- Identifying existence and form of heavy elements in our universe, whose emission can be observed in far-infrared and terahertz frequencies to elucidate emission from astronomical sources under formation and evolution.
- High angular resolution (less than 1 milli-arcsec) in FIR/THz is the key to study physical/chemical structure together with future facilities like ngVLA and TMT.

Narrabri Stellar Intensity Interferometer

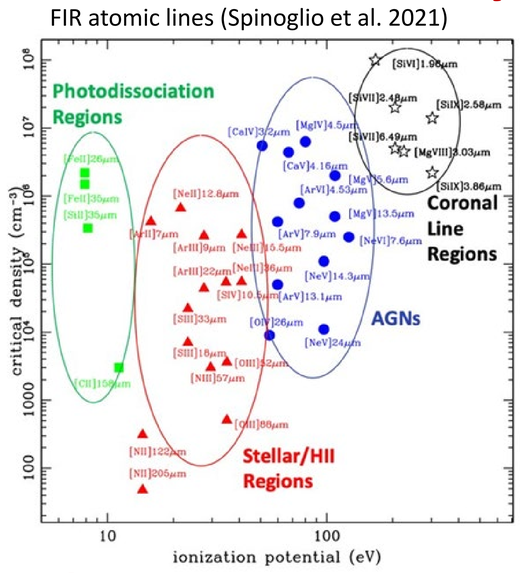


Importance of Far-IR and Terahertz Astronomy

Astronomical Background Radiation（Dole et al. 2006）



FIR atomic lines (Spinoglio et al. 2021)

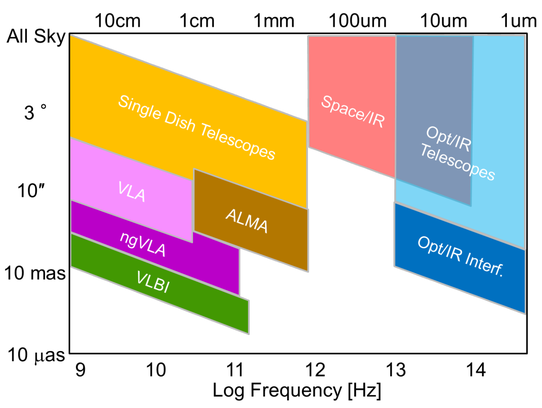


Comparison of Interferometer technologies

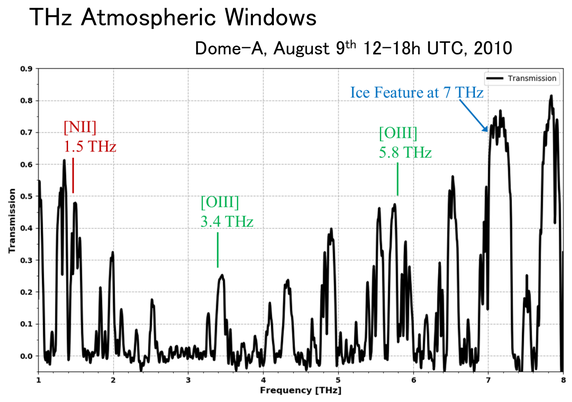
	Telescope	Wavelength	Sensitivity	Baseline	Tel Numb.	Phase Stab.	Imaging
Heterodyne Interf. (inc. VLBI)	warm 10 m	> 60 μm	×	Long	Any	×	○
Michaelson Interf. (Double Fourier)	cryogenic 1 m	25-400 μm	○	Short	Two	×	○
Intensity Interf.	cryogenic 3 m	30-300 μm	○	Long	Any	○	?

Observing condition in FIR/THz

Angular Scale of Observations



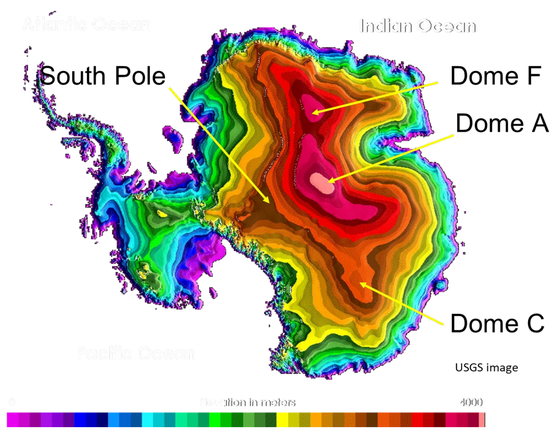
THz Atmospheric Windows



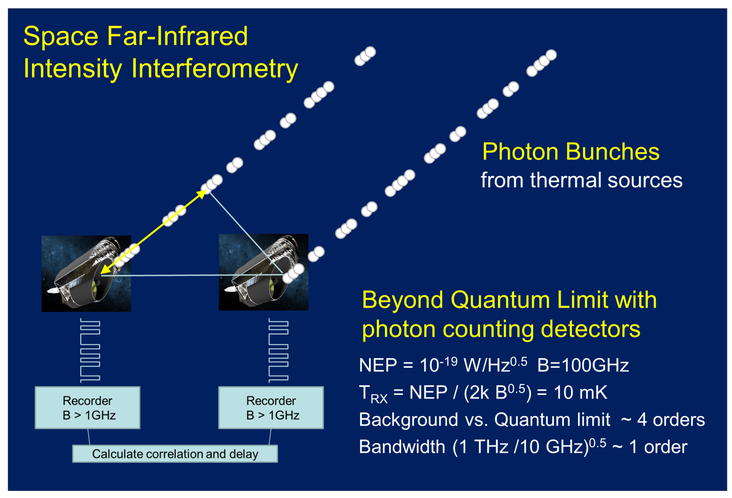
Matsuo et al. Advances in Polar Science (2019)

Long Baseline & High Sensitivity

Long baseline (Dome-A&F) Interferometry from Antarctica



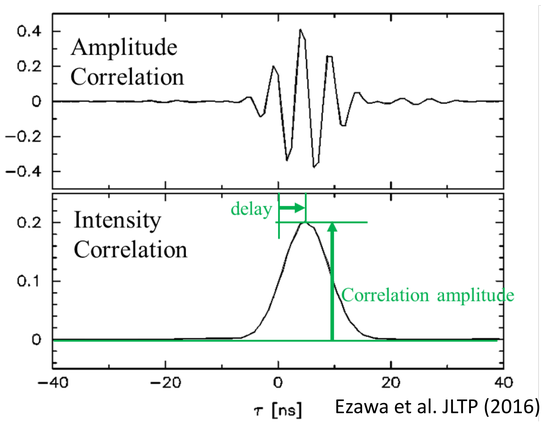
Background limited sensitivity from Space



Timelines

	2025		2030		2035		2040		2045
Technology Developments	Develop	Detector Imaging							
Antarctic THz Interferometer	Antarctic THz		30cm Exp. at D-F	1.5 THz [NII]		ATT12m and D-A			ATT30m and D-A	
Space FIR Interferometer	Space FIR		Pre Study	PRIMA	SILVIA	Phase A	Phase B	Phase C	Phase D	Launch

Intensity vs. Amplitude Correlations using Nobeyama Radioheliograph at 17 GHz .



Ezawa et al. JLTP (2016)

Antenna Temperature T_A^* [K]

System Temperature T_{sys} [K]

Frequency ν [Hz]

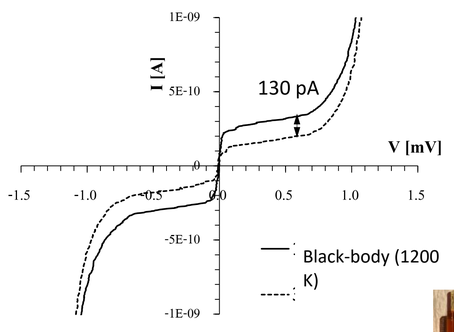
Bandwidth $\Delta\nu$ [Hz]

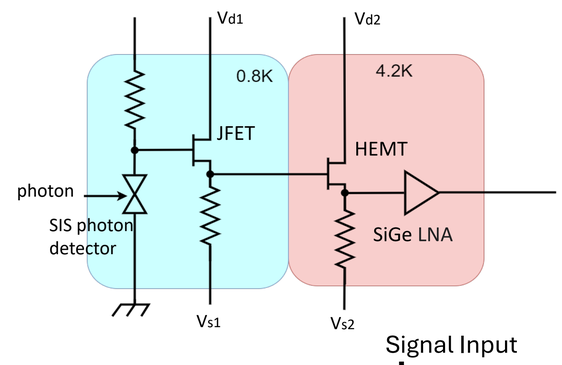
$$\Delta t = \frac{T_{sys}}{T_A^*} \cdot \frac{1}{\sqrt{\Delta\nu \cdot \tau}} \cdot \frac{1}{\Delta\nu} \text{[s]}$$

$$\Delta\varphi = 2\pi\nu\Delta t \text{ [rad]}$$

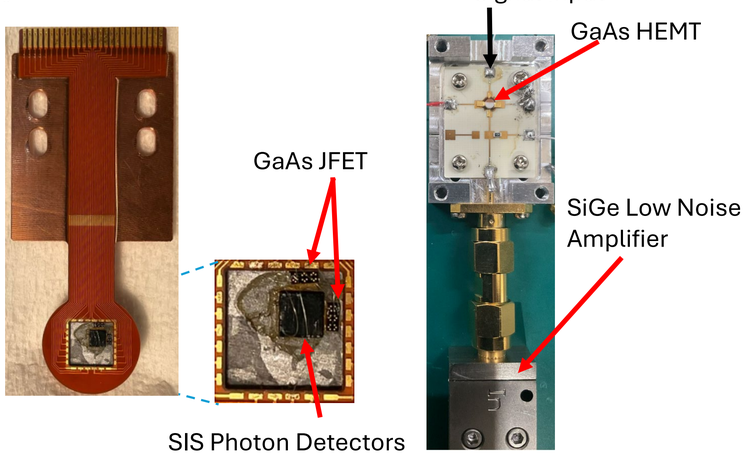
On-going Laboratory Demonstration of Intensity Interferometry using SIS Photon Detectors and Cryo-Electronics

SIS detector photo response

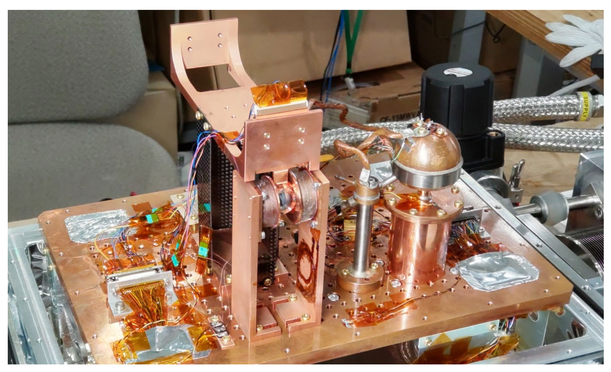




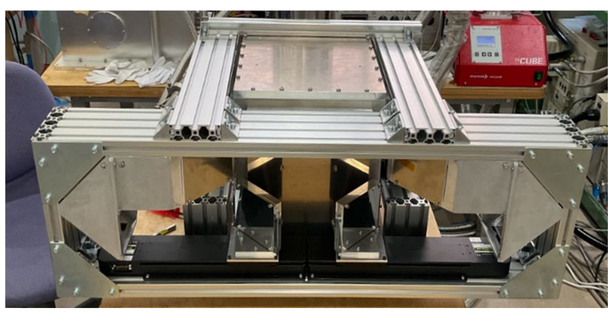
Fast cryogenic readout electronics is essential for delay time measurements.
Readout bandwidth of 10 MHz was achieved; several 100 MHz is foreseen.



Cryostat for THz experiment with 4K PTC, 0.8K sorption cooler and SIS photon detector.



Optical setups for Intensity Interferometry



Acknowledgements to JSPS KAKENHI Grant Numbers 18H05327/20K20346, 18H05326/20K20345 and JAXA basic R&D for future space science missions.