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# *Studies on Imaging Performance of Terahertz Intensity Interferometry*

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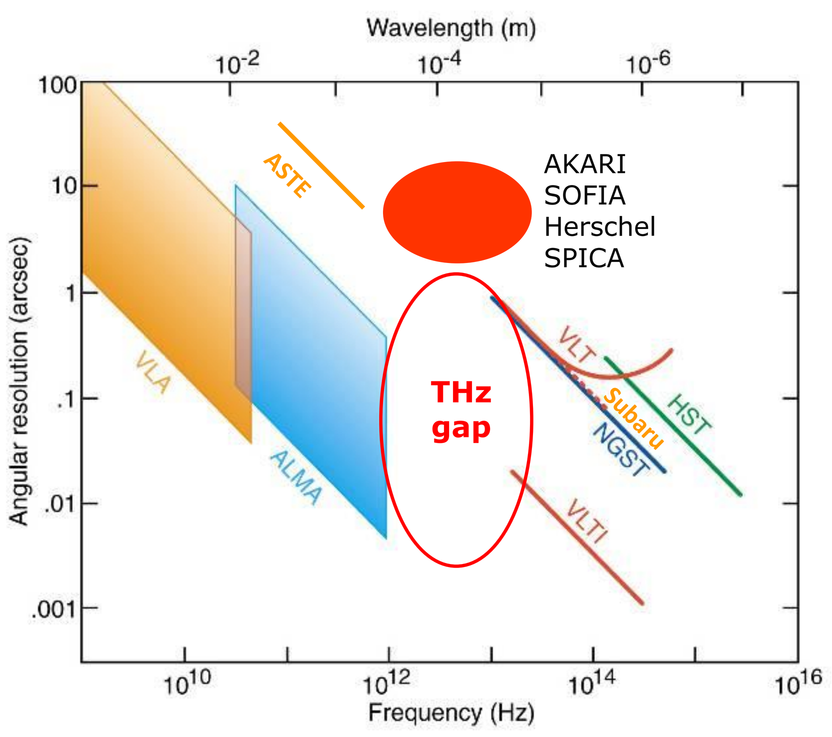
**ABSTRACT**

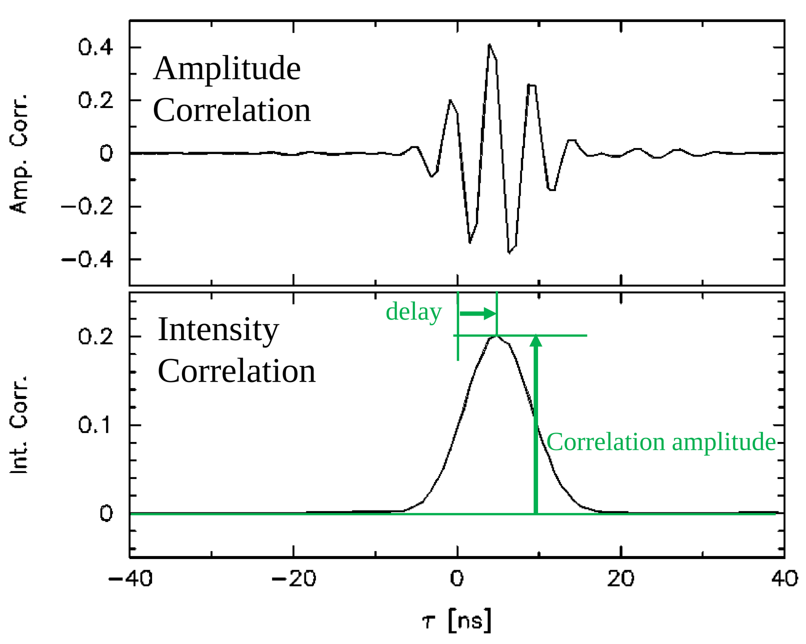
Future possibility of far-infrared and terahertz intensity interferometry in space is discussed. Fast photon counting detectors with 1 ns time resolution and NEP less than $10^{-17}$ W/Hz$^{0.5}$ can resolve all photon arrivals from bright far-infrared sources catalogued by AKARI. Intensity correlation due to photon bunches enable delay time measurements, and complex visibility is obtained for aperture synthesis imaging. Precise timing measurements on independent cryogenic telescopes and formation flights enable a long baseline intensity interferometer in space. The sensitivity gain of the photon counting detectors over heterodyne technologies can be as large as 6 orders of magnitude due to the background limited sensitivities and wide bandwidths. The THz intensity interferometers can resolve many compact AKARI sources with angular resolution better than ALMA, and resolve inner region of protoplanetary disks and active galactic nuclei.

## High Angular Resolution in THz astronomy



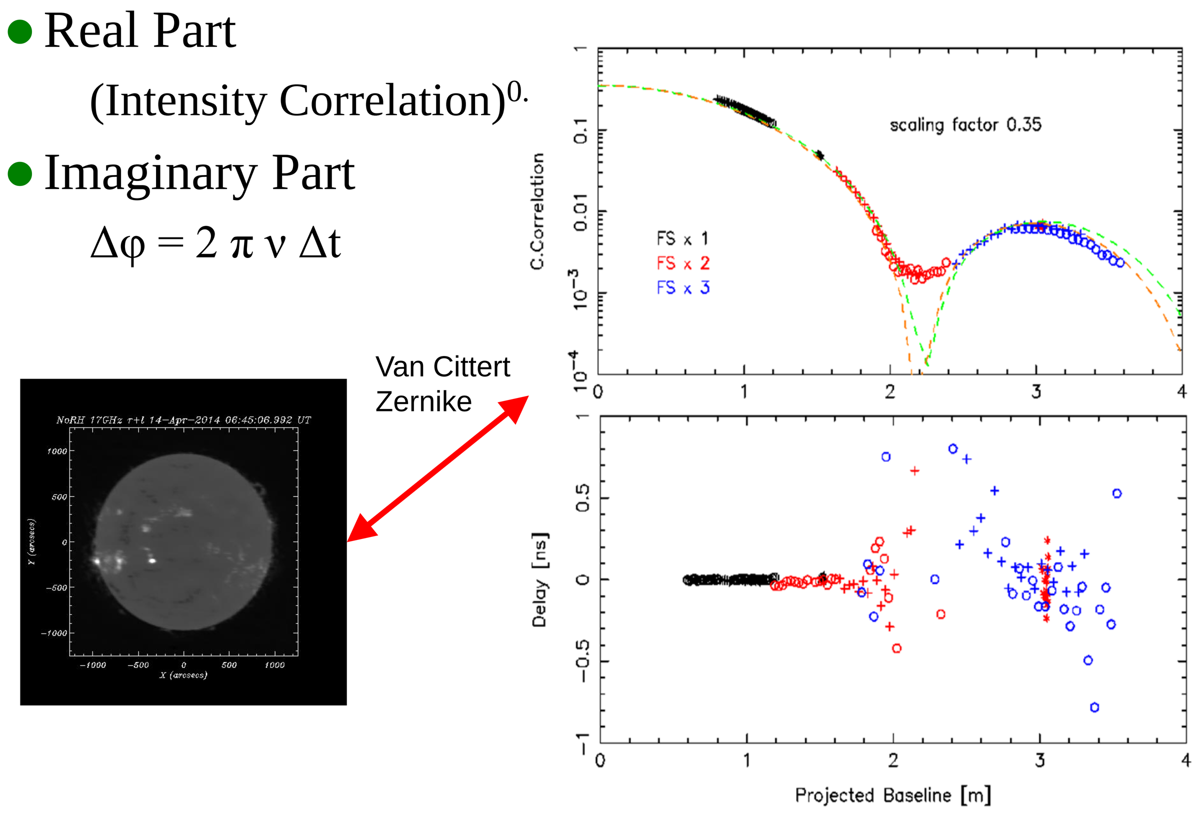

## Intensity Interferometer Experiment

with Nobeyama Radioheliograph 17GHz




## Complex Visibility for Aperture Synthesis Imaging

- Real Part
  (Intensity Correlation)$^{0.5}$
- Imaginary Part
  $\Delta\varphi = 2\pi\nu\Delta t$



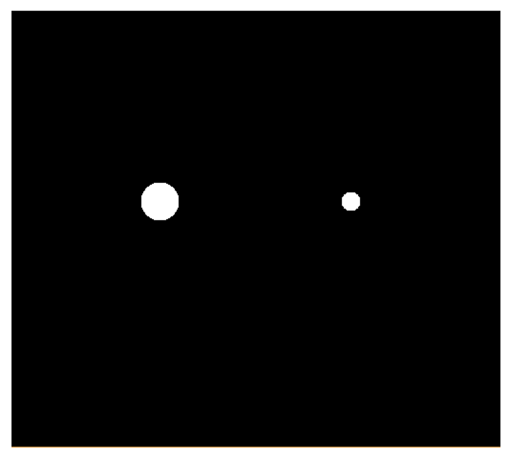

## Imaging Simulation of Amplitude and Intensity interferometers

Antenna Temperature $T_A^*$ [K]
System Temperature $T_{sys}$ [K]
Frequency $\nu$ [Hz]
Bandwidth $\Delta\nu$ [Hz]

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

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

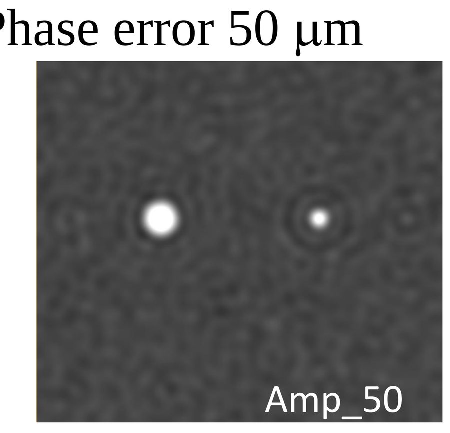
The model image



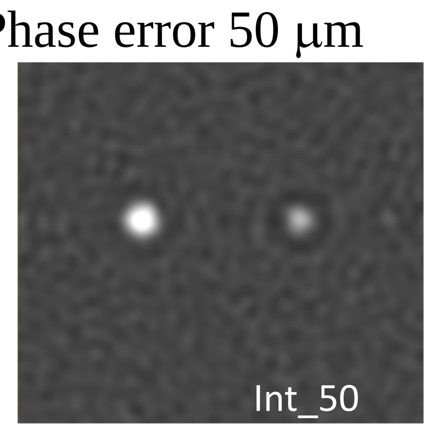
Betelgeuse like star with a companion.
$T_A^* = 0.13$ K, $T_{sys} = 500$ K, $\nu = 1$ THz

## Simulated Images

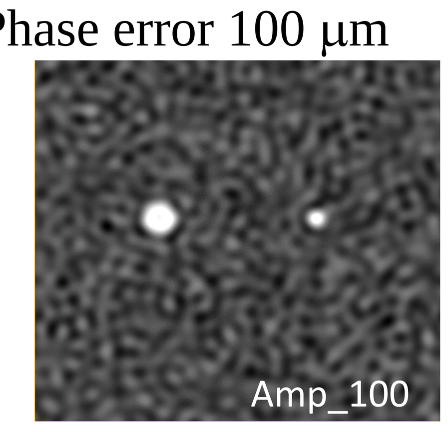
Amplitude
$\Delta\nu = 10$ GHz, t=60 sec
Phase error 50 μm



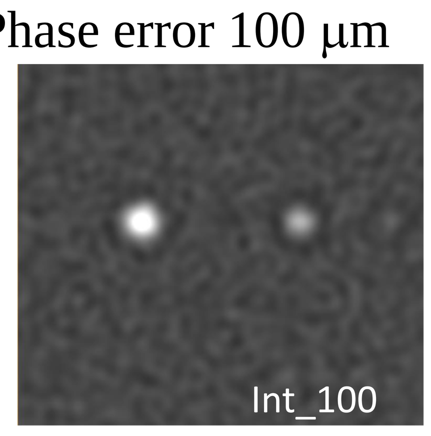

Intensity
$\Delta\nu = 100$ GHz, t=600 sec
Phase error 50 μm




Amplitude
$\Delta\nu = 10$ GHz, t=60 sec
Phase error 100 μm




Intensity
$\Delta\nu = 100$ GHz, t=600 sec
Phase error 100 μm



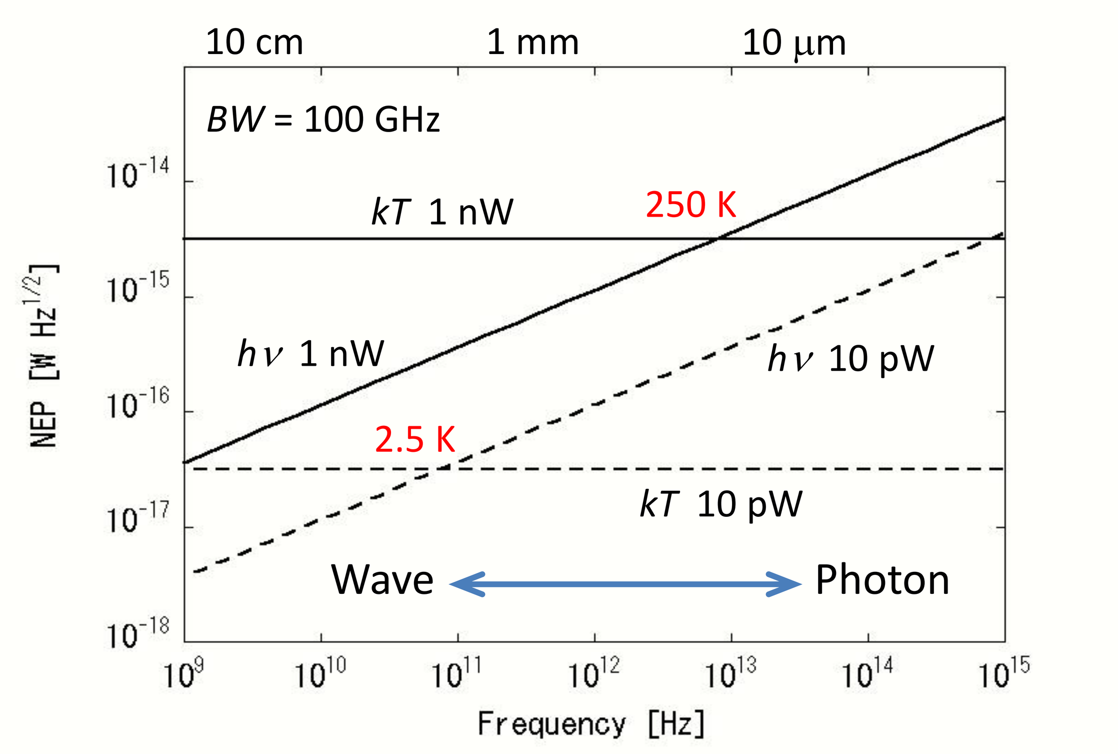

## What we have learned so far

- Intensity interferometers require high dynamic range measurements for aperture synthesis imaging.
- Photon counting detector is attractive to realize the high dynamic range.
- Intensity correlation is stable against phase noise.
- Visibility measurements on UV plane should be optimized for source distributions. (diffuse source is resolved out easily.)
- Most AKARI catalogued sources will be resolved by two small cryogenic telescopes in space.

## Thermal Photons are Bunched

$$\Delta n = \sqrt{n+n^2}\ ,\quad \text{where } n = \frac{1}{e^{h\nu/kT}-1}$$

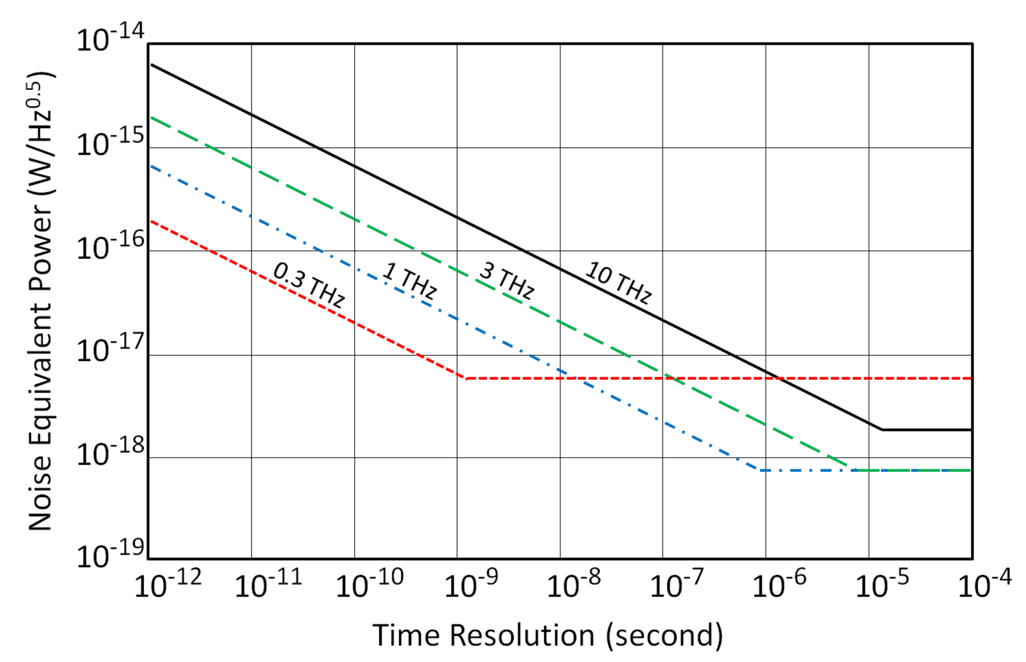
$$\mathrm{NEP} = \sqrt{2P\cdot(h\nu+kT_B)}\,[\mathrm{W}/\sqrt{\mathrm{Hz}}]$$




## Requirements to Detectors

- Background Limited Observation from Space
- Resolving all photon arrivals

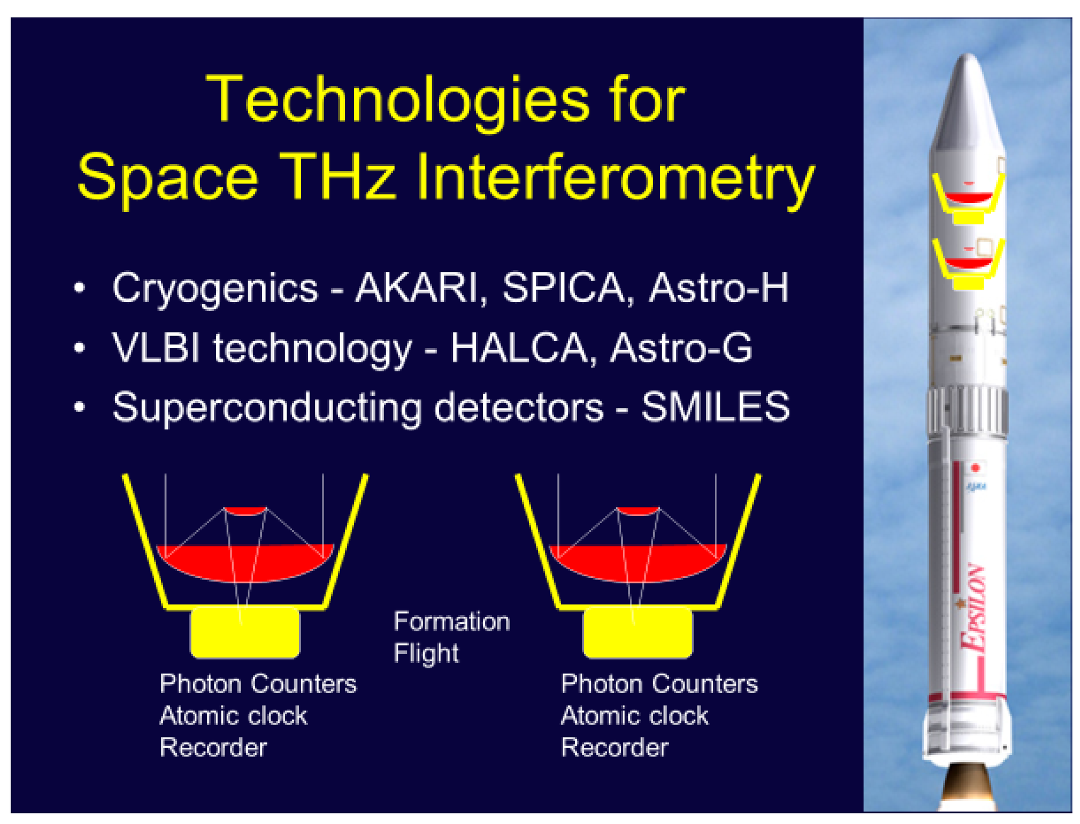
$\mathrm{NEP} = h\nu B^{0.5} = 10^{-21} \times (1\ \mathrm{GHz})^{0.5}$
$\sim 10^{-17}$ W/Hz$^{0.5}$




Photon counting detectors realize very low receiver noise temperature.

- No quantum limit with photon detectors
- $T_{rx} = \mathrm{NEP} / (2k\,B^{0.5}) = 20$ mK
  – when NEP = $5 \times 10^{-19}$ W Hz$^{0.5}$, B = 1 THz

## Technology for Space Terahertz Intensity Interferometry




References

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