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Photon Counting Terahertz Interferometry

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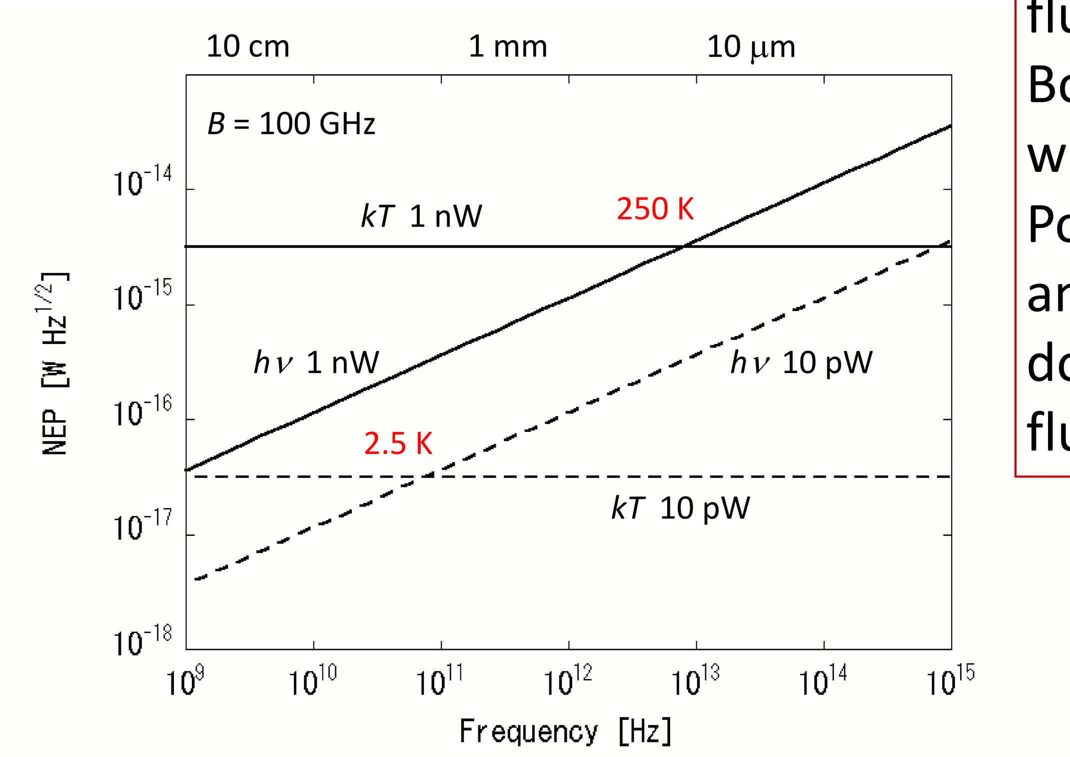
ABSTRACT

I have been proposing to apply Hanbury Brown & Twiss Interferometry to future *Terahertz Astronomy*. Some basic principles are discussed together with the future prospects of space based terahertz interferometry, the Photon Counting Terahertz Interferometry (PCTI). Combination of photon counting technologies with very long baseline interferometry, PCTI can be applied to very high angular resolution imaging of compact thermal sources such as exo-planets. Experimental demonstration using Nobeyama Radio Heliograph is presented, which realized delay time measurement within a wavelength.

Thermal photons are bunched

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

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



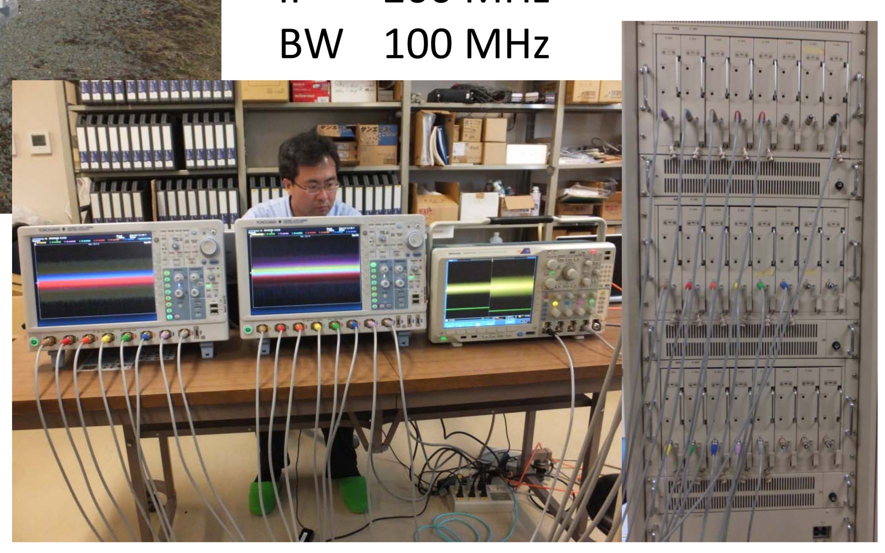
Thermal photon fluctuation is governed by Bose-Einstein statistics, which is larger than Poisson noise term ($h\nu$), and at longer wavelength dominated by wave fluctuation (kT_B).

Demonstrate Radio Intensity Interferometry

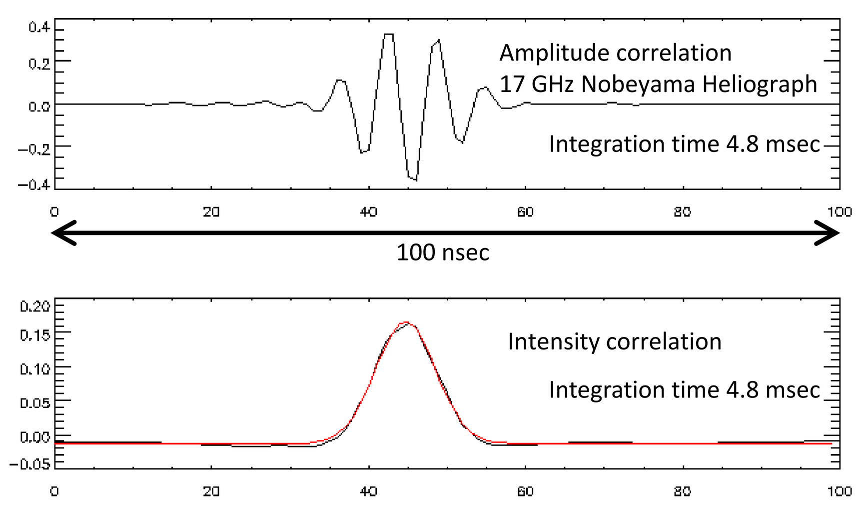
- Wide bandwidth, High sensitivity interferometer
- Nobeyama Radio Heliograph as an Intensity Interferometer.

April 7-15, 2014
Short baseline sampling with 16-element 80cm antennas

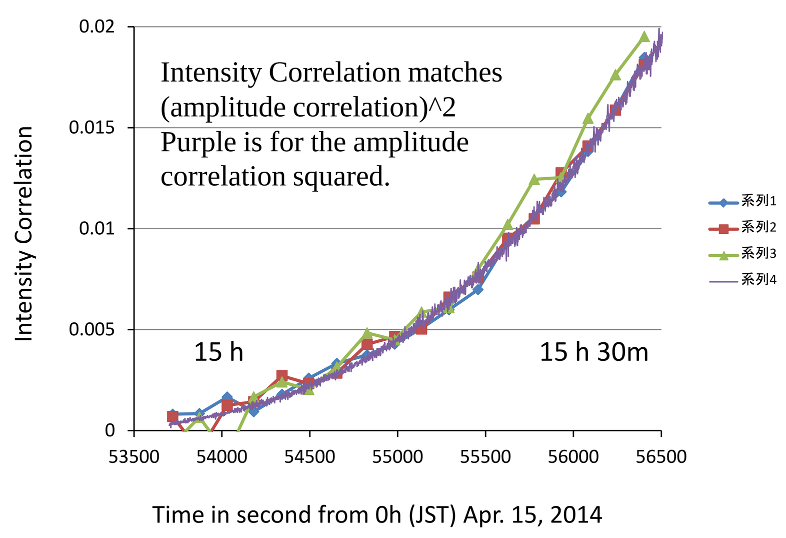
Uncooled HEMT Trx=360K
RF 17 GHz
IF 200 MHz
BW 100 MHz



Record 16ch IF signal for 50 msec with 2x Yokogawa DLM4058 (8ch 1.25 Gs/s, BW 500 MHz)



Correlation taken after smoothing out the phase information from amplitude-squared data.



Intensity Correlation matches (amplitude correlation)^2

Delay time accuracy

Δt = 8 psec (in 48 msec)

$\Delta t \times c$ = 2.4 mm vs. 17 GHz (λ=17 mm)

Delay time is determined within a wavelength

Number of photons in a bunch

400 photons/bunch

(τ= 1/2B = 5 nsec)

Members for the Heliograph experiment:
H. Matsuo (ATC/NAOJ)
H. Ezawa, M. Shimojo (ALMA/NAOJ)
K. Shibasaki, K. Iwai, N. Shinohara (NSRO/NAOJ)
M. Honma (VERA/NAOJ)
Y. Murata (ISAS/JAXA)

Photon bunching to measure delay time

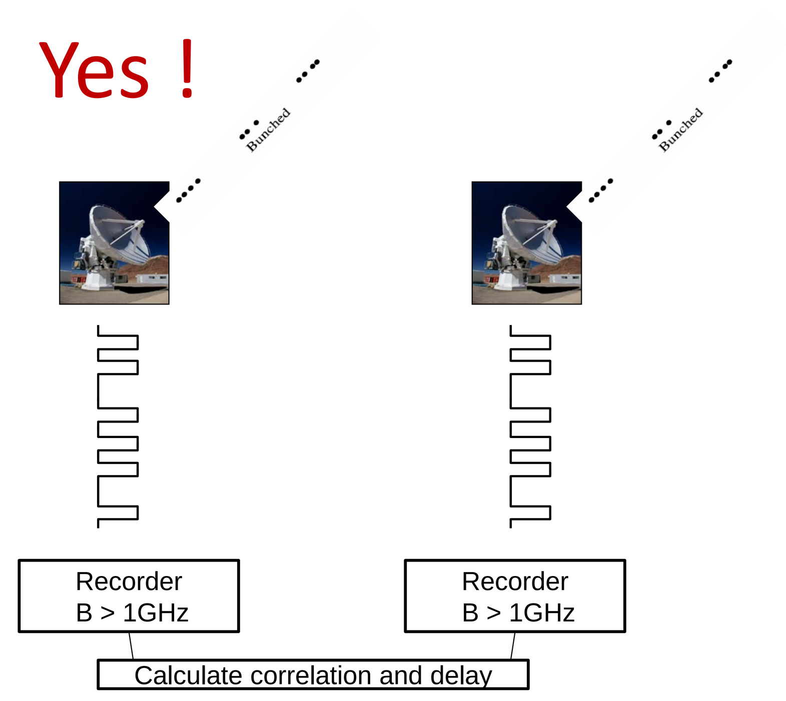
- Photon rate of 100 M photons/sec
  with 100 sec measurement,
  total number of photons is 10^{10}.
- Timing accuracy for one photon is
  1/100MHz = 10^{-8} sec.
- Statistical accuracy with 100 sec measurements
  10^{-8} sec / sqrt(10^{10}) = 10^{-13} sec

Timing accuracy better than a wavelength is expected !

Photon Counting VLBI ? Yes !

- Photon signal is recorded
  wide bandwidth > 1 GHz
- Good timing accuracy
  $dt < 10^{-13}$ sec

Technology Exist !



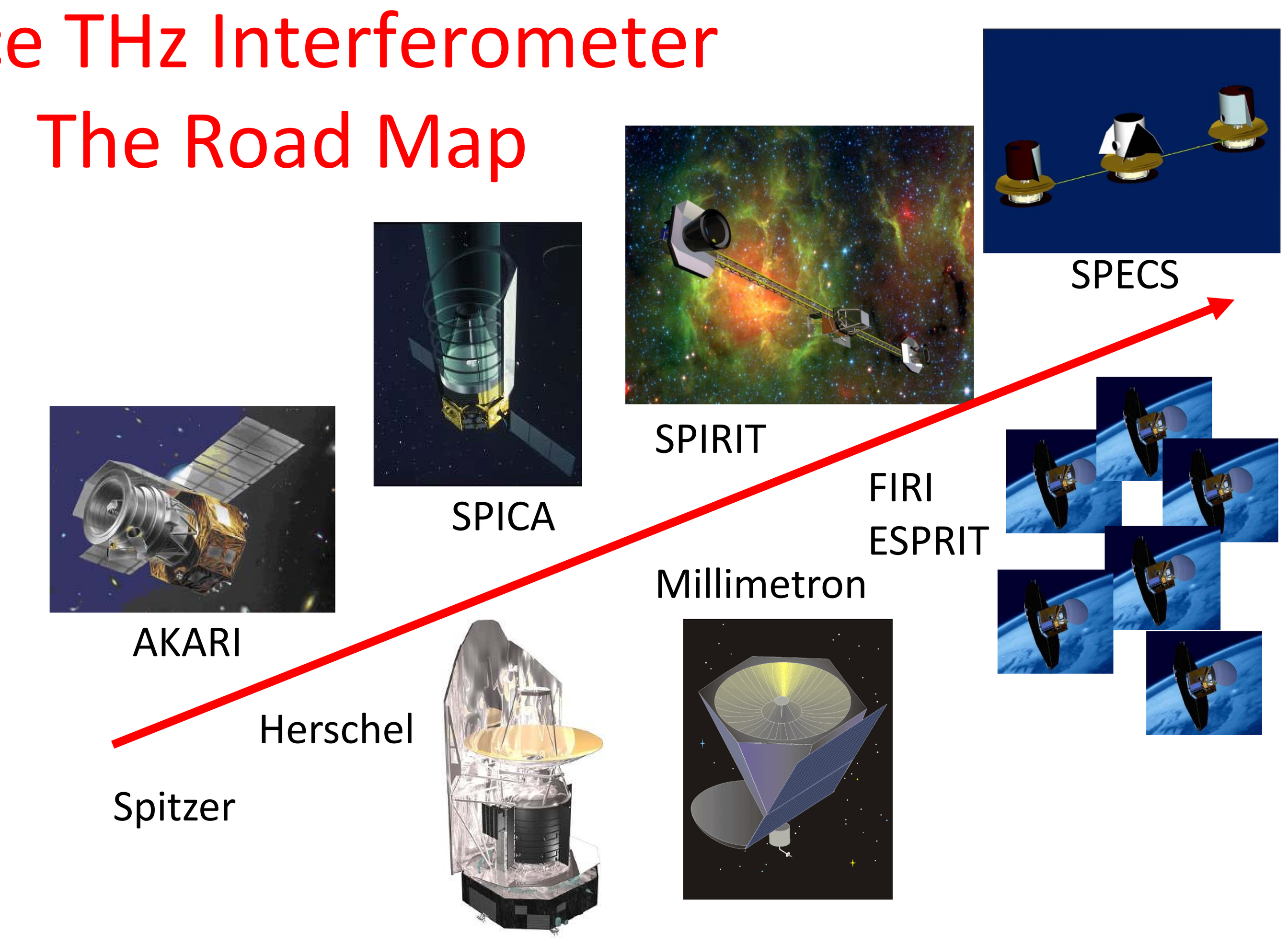
Photon Counting Terahertz Interferometry

- Free-flying cryogenic telescopes with photon counters
  High sensitivity interferometry
- Independent recording and post correlation analysis
  No limitation on the number of telescopes
- Intensity interferometry is insensitive to phase fluctuation
  High efficiency for high frequency interferometry

Observing capabilities with PCTI

FIR atomic lines from massive star-forming region
Imaging AGNs and Black-Holes
Imaging Stars and Exo-planets

Space THz Interferometer The Road Map



References
[1] H. Matsuo, "Requirements on Photon Counting Detectors for Terahertz Interferometry", Journal of Low Temperature Physics 167, pp. 840–845 (2012).
[2] H. Matsuo, "Fast and High Dynamic Range Imaging with Superconducting Tunnel Junction Detectors", Journal of Low Temperature Physics, (2013), DOI 10.1007/s10909-013-1022-3
[3] H. Nakajima et al. "The Nobeyama Radio Heliograph", Proc. IEEE 82, 705 (1994)