Photon Statistics as a Tool for Radio Astronomy

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Abstract

Photon statistics can be a new tool for astronomical observations. In terahertz frequency region, thermal photons are often bunched which create larger intensity fluctuation than random fluctuation of photons. Measurements of the input photon statistics would tell us more than their intensity, such as the brightness temperature of sources as well as the time delay of intensity fluctuation using the bunched photon arrivals. By developing fast photon counting detector in terahertz frequencies using superconducting tunnel junction detectors, it will be possible to characterize terahertz emission sources and making use of them for photon counting terahertz interferometry (PCTI).

1. Introduction

The first usage of photon statistics was the intensity interferometry demonstrated by Hanbury-Brown and Twiss[1] in 1950's, where intensity fluctuation was used to measure cross correlation of intensity fluctuation from two telescopes as a function of baseline length. The intensity interferometry was demonstrated both in radio and optical observations, but they suffered from low correlation efficiency and missing phase information, and their applications were limited. Application of photon counting detectors in terahertz frequencies would solve both of these problems.

2. Photon Statistics

The Bose-Einstein statistics of thermal photon predicts that photon statistics changes from random fluctuation to bunched photon fluctuation when source brightness temperature is higher than 3-300 K in terahertz frequencies. Figure 1 shows the random fluctuation of photon ($h\nu$) and coherent fluctuation (kT) as a function of brightness and frequency. So, the photon statistics can be a measure of source brightness temperature for most astronomical sources. Because of large number of photons in terahertz frequencies, very precise measurements of source physics would become possible, such as deviation from thermal equilibrium. Other emission mechanism such as non-thermal synchrotron sources, the photon statistics would tell us distribution of electron in the plasma and electron bunches could be resolved.

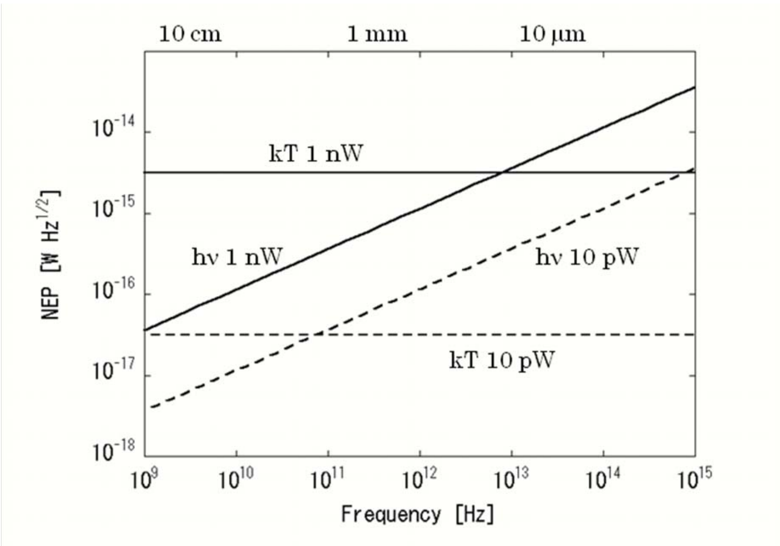

Fig. 1. Fluctuation of thermal radiation plotted for photon fluctuation and coherent fluctuation separately[2]. Bandwidth of 100 GHz is assumed. 1 nW correspond to brightness temperature of 250 K, whereas 10 pW for 2.5 K.

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3. Photon Counting Terahertz Interferometry

Here I introduce photon counting technologies in terahertz frequencies to combine with the intensity interferometry. This will realize high cross-correlation efficiency and delay time measurements using photon bunches. This technology can be called as photon counting terahertz interferometry, or PCTI[2]. The technology will be useful to realize very long baseline interferometry using photon counting detectors. When applied to future far-infrared space interferometry, very high sensitivity and very high angular resolution observations will become possible and exo-planets around nearby stars would be resolved.

To realize the photon counting detectors in terahertz frequencies, I propose to use superconducting tunnel junction detectors[3]. Using niobium-based tunnel junction, photon-assisted tunneling is observed below the gap frequency at around 700 GHz, and pair breaking process become important at higher frequencies. In either of the detection process, antenna-coupled small tunnel junctions are beneficial for fast photon counting at a rate of 100 Mphotons/sec. High quality low leakage junctions are essential to reduce dark counts of the detectors. Readout electronics will be a combination of low gate-leakage GaAs-JFETs with microwave amplifiers to realize low noise and fast readout electronics. Their design details and experimental progresses will be presented.

4. Evaluation using existing interferometry

Evaluation of intensity interferometry in view of photon statistics is ongoing using existing radio interferometers. Preliminary results show that high signal-to-noise ratio data enables measurements of delay time accurate enough to calculate aperture synthesis images using intensity interferometry.

5. References

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