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APPENDIX: LIMITS ON THE USE OF HETERODYNING
AND AMPLIFICATION IN OPTICAL INTERFEROMETRY

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The development of optical fibers, lasers, and mixers at optical frequencies has offered the hope that active methods can contribute to optical interferometry. Heterodyning, in particular, looks attractive, even though bandwidths are narrower than one would like at present; one might expect this limitation to lessen as technology develops. That expectation, unfortunately, is not likely to benefit interferometry at optical wavelengths because of the intervention of quantum mechanics and the second law of thermodynamics, as Burke (1985a) pointed out. So much "second quantization" noise is generated that only at infrared frequencies, somewhere in the 10-100 micron range, can one look forward to heterodyning in any realistic sense.

The reason is easily understood. Every amplifier, in the quantum limit, works by stimulated emission, even though this basic truth is not obvious at radio frequencies. This means that there must be spontaneous emission occurring within every amplifier, and Strandberg (1957) showed that this implied a limiting noise temperature, $T_N = h\nu/k$, for any amplifier. Burke (1969) used this result to demonstrate that, if it were not for this quantum noise, the VLBI method would allow one to tell which slit a photon went through before forming an interference pattern, thus violating basic tenants of quantum mechanics. In essence, the second quantization condition $\Delta N \Delta \phi \geq 1$ saves one from paradox. One can state the conclusion simply: any amplifier produces approximately one photon per Hertz of bandwidth. In optical interferometry, one will certainly want bandwidths in the 10^{12} - 10^{14} Hz range, and that implies an intolerable cacophony of noise photons.

Only at infrared frequencies can one tolerate the quantum noise, where the natural noise background may be high and the mixers are not as efficient as one would hope for. The crossover at present is about 10 or 20 microns, but the boundary will shift to longer wavelengths as noise performance improves. One might guess that ultimately a wavelength of about 100 microns will mark the limit of useful amplification and heterodyning in astronomical aperture-synthesis interferometry. At shorter wavelengths, amplification or heterodyning can only degrade the signal-to-noise ratio.

References

1. Strandberg, M.W.P. 1957. Inherent Noise of Quantum-Mechanical Amplifiers, *Phys. Rev.* 106: 617.
2. Burke, B.F. 1969. Quantum Interference Paradox, *Nature* 223:389.