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R. F. Chang

R. W. Detenbeck

V. Korenman

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R. F. Chang
R. W. Detenbeck†
V. Korenman

Department of Physics and Astronomy
University of Maryland, College Park, Maryland

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†Department of Physics, University of Vermont, Burlington, Vermont.

Abstract

The 2nd, 3rd and 4th cumulants of the distribution of light intensity from a He-Ne laser operating just below threshold have been measured as counting time is increased. The results agree with predictions computed under the assumption that the dependence of the correlation functions on the time variables is the same as for Gaussian light.

PHOTON STATISTICS FOR THRESHOLD LASER LIGHT WITH FINITE COUNTING TIMES*

Early measurements of correlations of intensity fluctuations in well stabilized He-Ne lasers operating near threshold reported only the correlations of fluctuations all at the same time [1,2]. These determined the probability density of instantaneous samples of the intensity (I.P.D.). Recent studies [3,4] have provided the time dependence of the two-time correlation function in the threshold region. All these results have been consistent with current laser theories based on the Fokker-Planck equation with Markoffian noise sources [5-10].

We add here measurements of the time dependence of the first four normalized cumulants for counting times from 3 to 1000 microseconds, for a laser operating slightly below threshold where the fluctuation time is about 100 microseconds. What is measured is an average over each of the time variables of the correlation of intensity fluctuations at different times, as a function of the averaging time, T. This can be considered as defining an effective I.P.D. which is a function of T.

The T dependence of this effective I.P.D. is not determined by its T = 0 limit, the usual I.P.D. In what follows we compare our results with a time dependence computed under the assumption that the dependence of the correlation functions on their time variables is that of Gaussian light. The time dependence of higher correlations can also be computed from the Fokker-Planck equation with Markoffian noise [5-10]. Unfortunately all the coefficients needed for such a computation have not been calculated

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in the literature, but a preliminary study implies that for our conditions the result would not be noticeably different from the simple assumption above.

For Gaussian light the nth cumulant of the effective I.P.D. is [11,12]

$$K_n(T) = K_n(0) \int_0^T \gamma(t_1 - t_2)\gamma(t_2 - t_3). . . \gamma(t_n - t_1)\, dt_1. . .dt_n \quad (1)$$

where γ is the normalized field auto-correlation function. The spectrum of γ is Lorentzian in our region of operation, chosen to be below threshold in order that Q_3 and Q_4 be sensibly different from zero.† For a Lorentzian spectrum, following eq. (1), the cumulants are [13]

$$Q_2(T)/Q_2(0) = 2Z^{-1} + 2(e^{-Z} - 1)Z^{-2}, \quad (2a)$$

$$Q_3(T)/Q_3(0) = 6(e^{-Z} + 1)Z^{-2} + 12(e^{-Z} - 1)Z^{-3}, \quad (2b)$$

$$Q_4(T)/Q_4(0) = 8e^{-Z}Z^{-2} + 20(2e^{-Z} + 1)Z^{-3} + 2(e^{-2Z} + 28e^{-Z} - 29)Z^{-4}, \quad (2c)$$

where $Z = \Gamma T$, Γ is the half width at half maximum of the intensity power spectrum and $Q_n(T)$ is the nth normalized cumulant [1].

Our measurements were made with the equipment and technique reported previously [1], recording photoelectron distributions with various counting times for laser intensities of 17% and 42% of the threshold value.

A least squares fit was made of the data $Q_2(T)$ to (the logarithm of) Eq. (2) using $Q_2(0)$ and Γ as parameters. The same value of Γ was then used for the $Q_3(T)$ and $Q_4(T)$ data, adjusting $Q_3(0)$ and $Q_4(0)$ for the best fit. Fig. 1 shows data for $Q_n(T)/Q_n(0)$ along with eq. (2).

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†Theory [5,8] and experiment [3,4] agree that below threshold the spectrum of γ is quite accurately a Lorentzian.

The good fit to our simple *ansatz* above seems to imply that in the region under study where the static intensity correlations are already quite different from their Gaussian limits, the dynamic correlations can still be described by the simple one-decay-time approximation appropriate to Gaussian light. At higher intensities, closer to and above the threshold, we expect deviations from this simple result.

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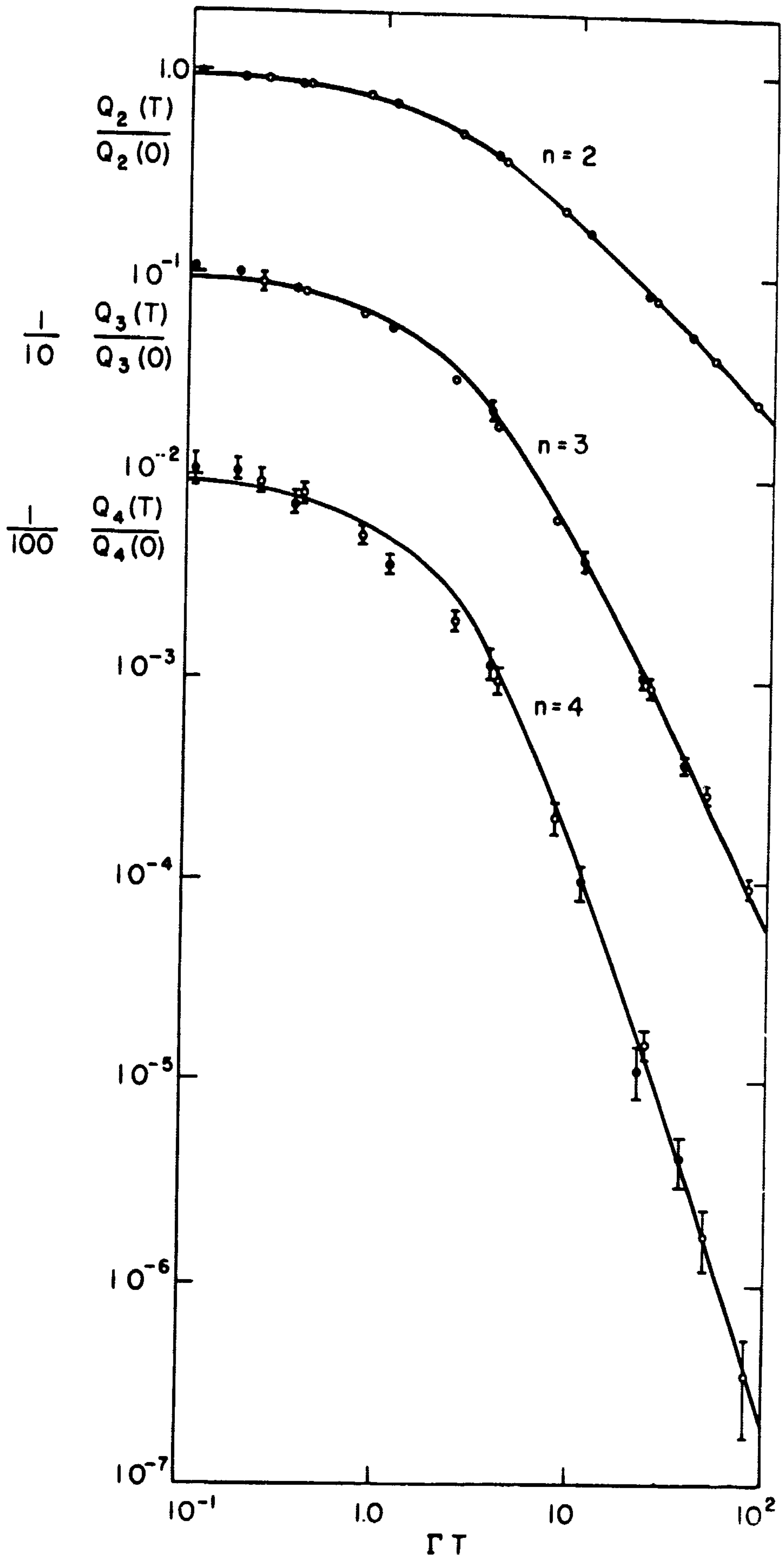
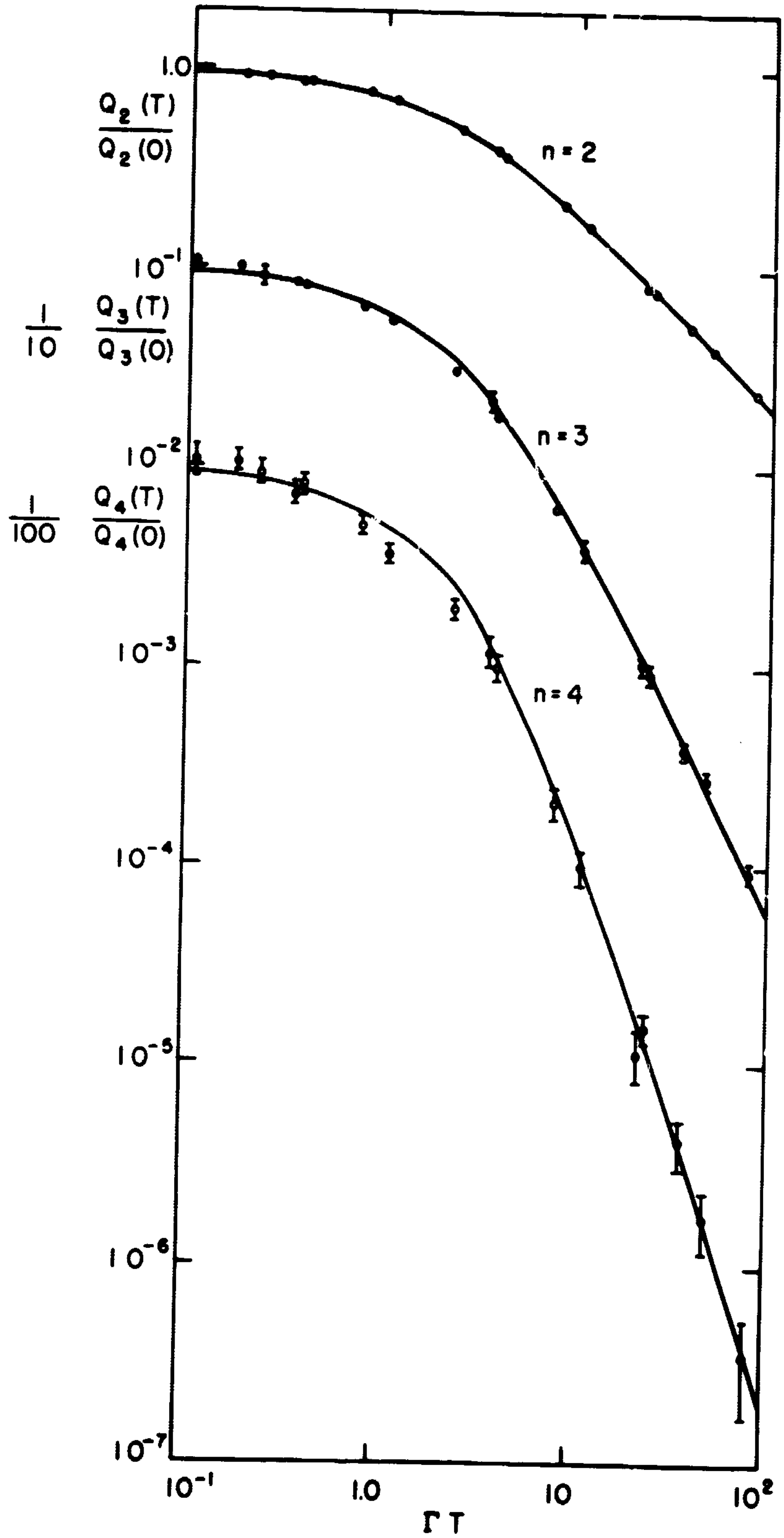
Fig. 1 Open circles are values of $Q_n(T)/Q_n(0)$ at 17% of threshold. Solid circles are at 42% of threshold. Statistical standard deviations are shown when larger than dot size. The curves are the predictions of Eq. (2).



1.0
$\frac{Q_2(T)}{Q_2(0)}$
n = 2
10^{-1}
$\frac{1}{10}$ $\frac{Q_3(T)}{Q_3(0)}$
n = 3
10^{-2}
$\frac{1}{100}$ $\frac{Q_4(T)}{Q_4(0)}$
n = 4
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-1}
1.0
10
10^{2}
Γ T

Fig. 1



1.0
$\frac{Q_2(T)}{Q_2(0)}$
10^{-1}
$\frac{1}{10}$ $\frac{Q_3(T)}{Q_3(0)}$
10^{-2}
$\frac{1}{100}$ $\frac{Q_4(T)}{Q_4(0)}$
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
n = 2
n = 3
n = 4
10^{-1}
1.0
10
10^{2}
ΓT