Faculty of Physics, Moscow State University Department of Optics, Spectroscopy and Physics of Nanosystems

Senior researcher A. M. Zotov, Professor P. V. Korolenko and post-graduate student N. N. Pavlov present

PROPERTIES OF FRACTAL SPECKLE FIELDS. THEORY AND APPLICATIONS

The aim of the work was to construct an optical-physical model to analyze the processes of formation and propagation of speckle fields with different statistical and scaling characteristics. Much attention was paid to the development and software implementation of the algorithms that provide the possibility of varying the statistical and fractal parameters of speckle beams in the initial plane and at different distances from it over a wide range.

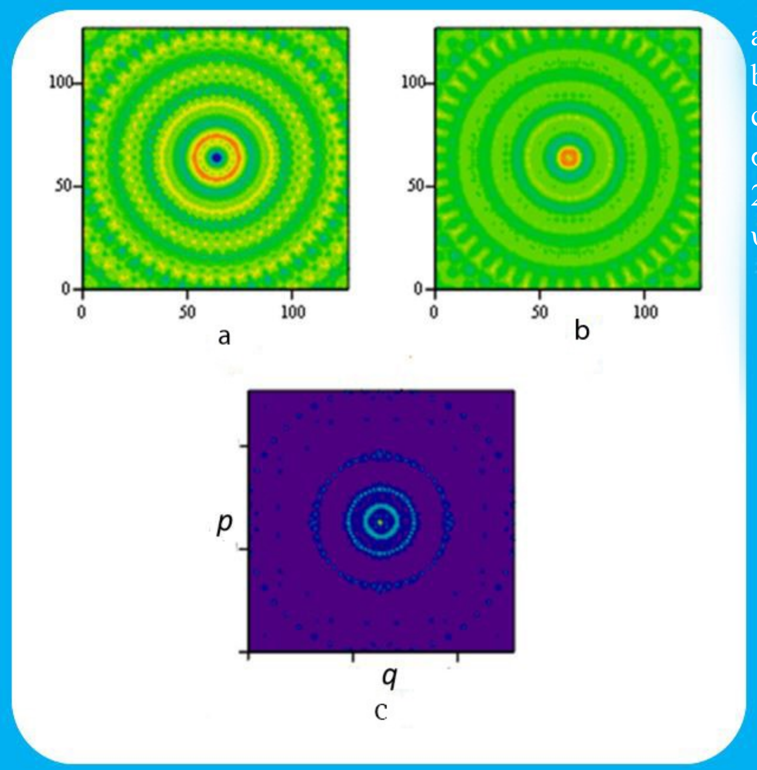
CALCULATION MODEL

$$W_{x,y} = \sigma \sum_{v=0}^{V} \sum_{n=0}^{N} \frac{[1 - e^{ib^n s[(x-\eta)\cos(\alpha v) + (y-\eta)\sin(\alpha v)]}] e^{i(\psi_n k_1 + \psi_v k_2)} e^{i\zeta \alpha v}}{b^{(2-D)n}}$$

$$\psi_i = \frac{2\pi \cdot rnd(i)}{(i+1)}$$

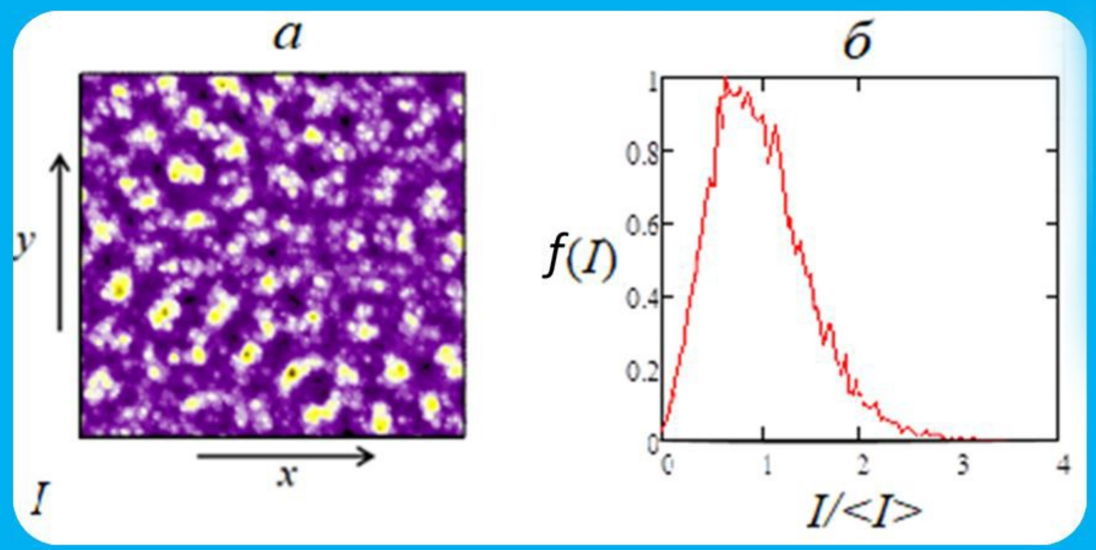
The value W determines the field amplitude, the discrete transverse coordinates are $0 \le x,y \le K-1$ (K is an integer), D characterizes the fractal dimension, s is the scaling parameter, b is the scaling coefficient; σ is the normalization factor; n is the harmonic number; v is the azimuthal index; $\psi_{n,v}$ are phases of harmonics and azimuthal partial waves; α is the unit angle of rotation of the amplitude-phase distribution; k1, k2, η, ς are numerical parameters.

REGULAR STRUCTURES. ART THERAPY



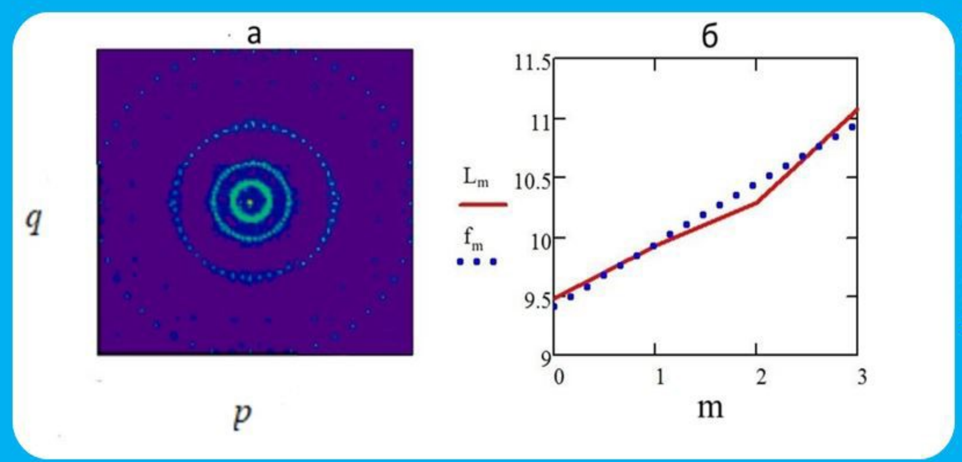
a) - amplitude distribution
b) - phase distribution
c) - spatial spectrum
$\sigma = 0.3$, $D = 1.3$, $s = 0.4$, $b = 2$, $N = 6$, $V = 47$, $\alpha = 2\pi/48$, $K = 127$, $\eta = (K+1)/2$, $\varsigma = 0$, $k1 = 1$, $k2 = 0$, ψn, ψv – random

NONRAYLEIGH SPECKLE



a - intensity distribution
b - the probability density distribution

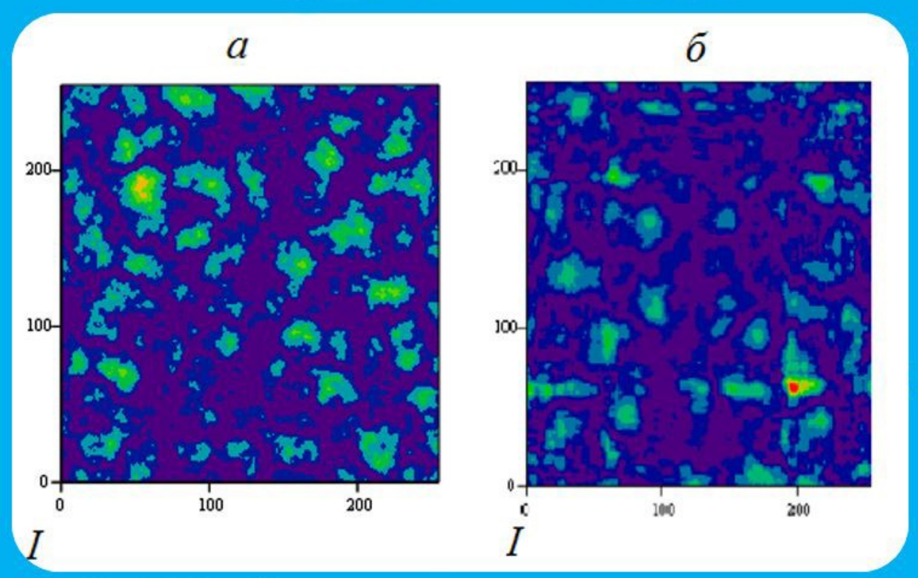
STRUCTURE OF THE SPATIAL SPECTRUM



a - spatial spectrum
b - behavior of the structural function
p, q are spatial frequencies, fm is a straight line approximating the dependence Lm=log2Cm

$$C_m = \frac{1}{(K - 2^{2m})} \cdot \sum_{x=0}^{K-2^m} \sum_{y=0}^{K-2^m} \left| I_{x+2^m,y} - I_{x,y+2^m} \right|$$

DISTRIBUTION OF SPECKLES IN SPACE



a - the initial field,
b - image of the initial field

Plane wave decomposition, FFT

$S = cfft(W)$

$$c(t) := \mathrm{mod}\left(t + \frac{N}{2}, N\right) - \frac{N}{2}$$

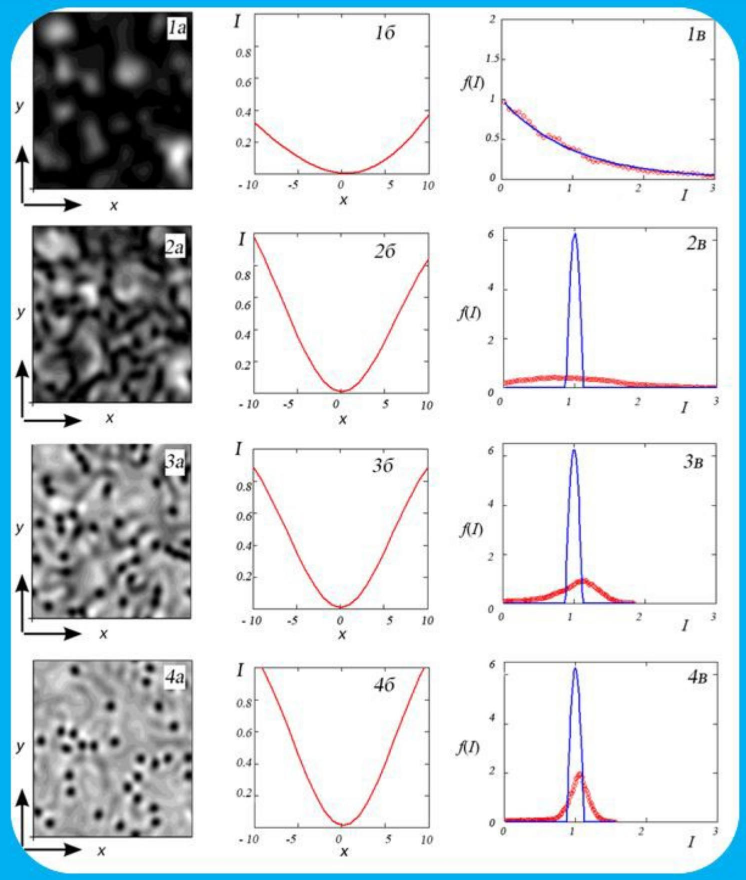
$$S_{x,y} := S_{x,y} \cdot \exp\left[i \cdot 2\pi\ zT \cdot \left(c(x)^2 + c(y)^2\right)\right]$$

Plane wave assembly, inverted FFT

$B1 := icfft(S)$

$I_{x,y} = (|B1_{x,y}|)^2$

TRANSFORMATION OF THE DISLOCATION STRUCTURE BY THE GS METHOD



Change in the characteristics of the speckle field during the use of the HS procedure. 1a, 1b, 1c – characteristics of the initial field; 2a, 2b, 2c – field after the 1st iteration; 3a, 3b, 3c – field after the 10th iteration; 4a, 4b, 4c – field after the 1000th iteration. 1a - 4a - intensity distribution over transverse coordinates x, y; 1b - 4b - average change in intensity I near the dislocation point (the transverse coordinate x is measured by the number of pixels); 1c - 4c - plots of the probability density f(I) (blue color 1c - Rayleigh probability density, 2c-4c - the target probability density setting, red - implemented as a result of the calculation).

CONCLUSIONS

An approach has been developed for modeling fractal speckle fields, which allows varying the scaling and statistical parameters of radiation over a wide range. This property makes them very useful for improving techniques used in biomedicine.

The developed algorithms can be used for software operation of spatial light modulators that form light beams with a fractal structure.

It was shown that the transition from the Rayleigh statistics of the speckle intensity distribution to the non-Rayleigh one does not affect the scaling properties of light beams within the framework of our model.

With regard to systems that provide the construction of optical images it has been established that the image of a speckle structure has the same fractal dimension as the original field.

The effect of reducing the size of wavefront dislocations in speckle fields with non-Rayleigh statistics indicates the possibility of using it to realize spatial superresolution in phase images.

LITERATURE

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