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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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WINTER COLLEGE ON OPTICS

9 - 27 February 1998

The Fundamentals of Speckles and their Applications

Part II

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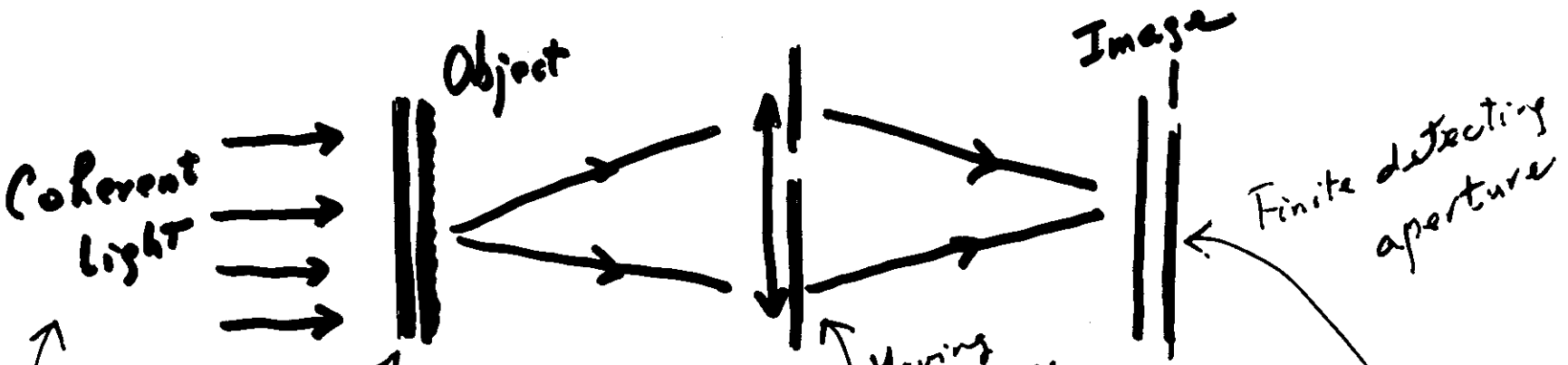
Superposition of speckles

noise

Speckle reduction

↓

Image improvement



Reduction of speckles (noise)

⇓

Image improvement

① Temporally partially coherent light

② Spatially partially coherent light

③ Time-averaging by means of the moving aperture

④ Space-averaging by means of the finite detecting aperture

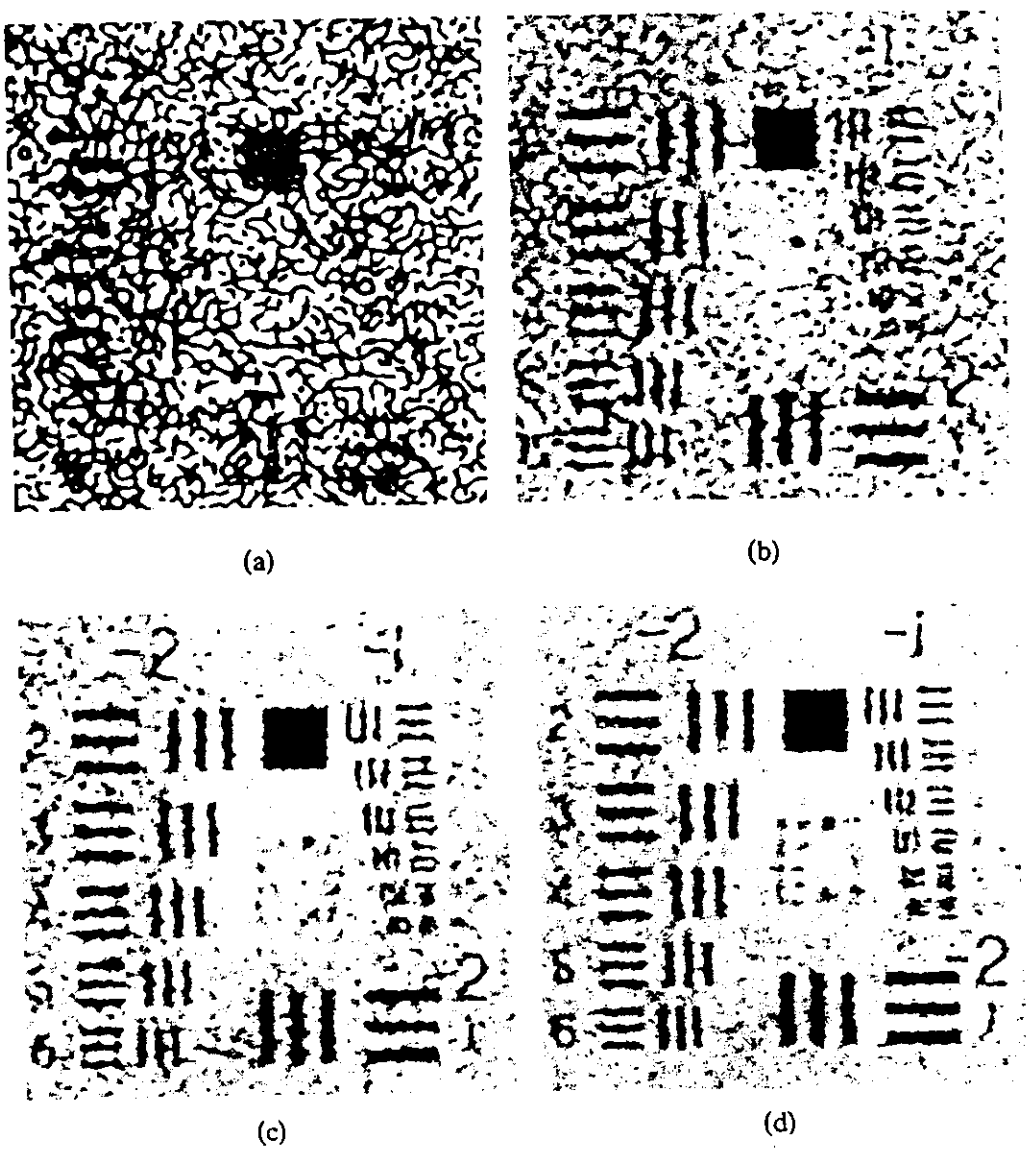


Fig. 13. Photographic images obtained for exposure time $T = 50$ s through a stationary aperture of width $W = 0.35$ mm with radius $R = 1{\cdot}0$ mm (a), and through a rotating aperture of width $W = 0.35$ mm with $R = 1{\cdot}0$ mm (b), $3{\cdot}0$ mm (c), and $8{\cdot}0$ mm (d).

Dynamic speckles

Two fundamental motions of speckles

Boiling
Translation
} Mixed state of boiling and translation

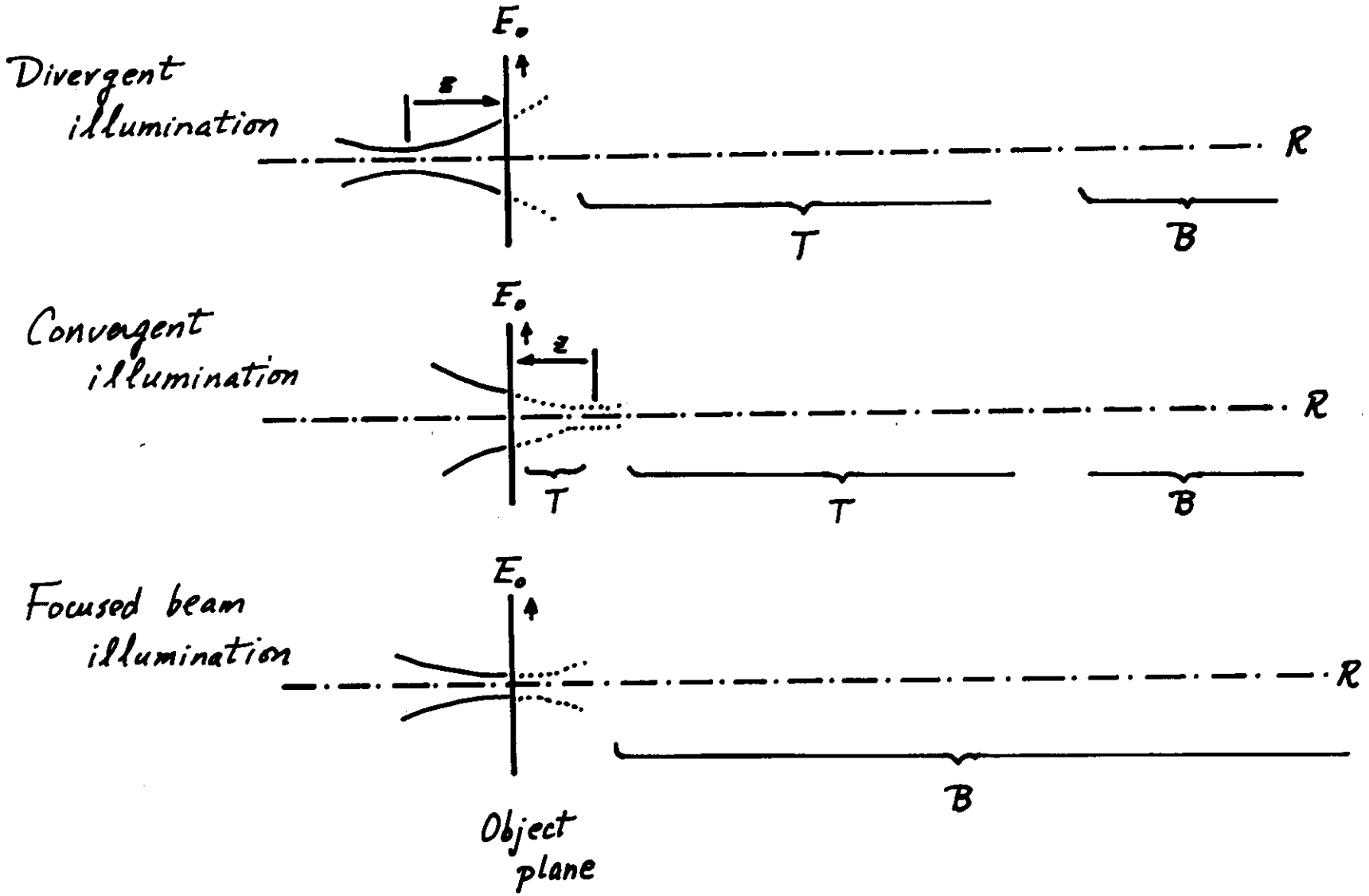
Characteristics dependence of dynamic speckles

Motion of the diffuse object ⟶ Velocity measurements

Parameters of the optical systems including the conditions of illumination and detection

Fundamental physical quantity: Space-time correlation of the speckle field

Regions of boiling [B] and translation [T]



Velocity measurement of the diffuse object using dynamic speckles

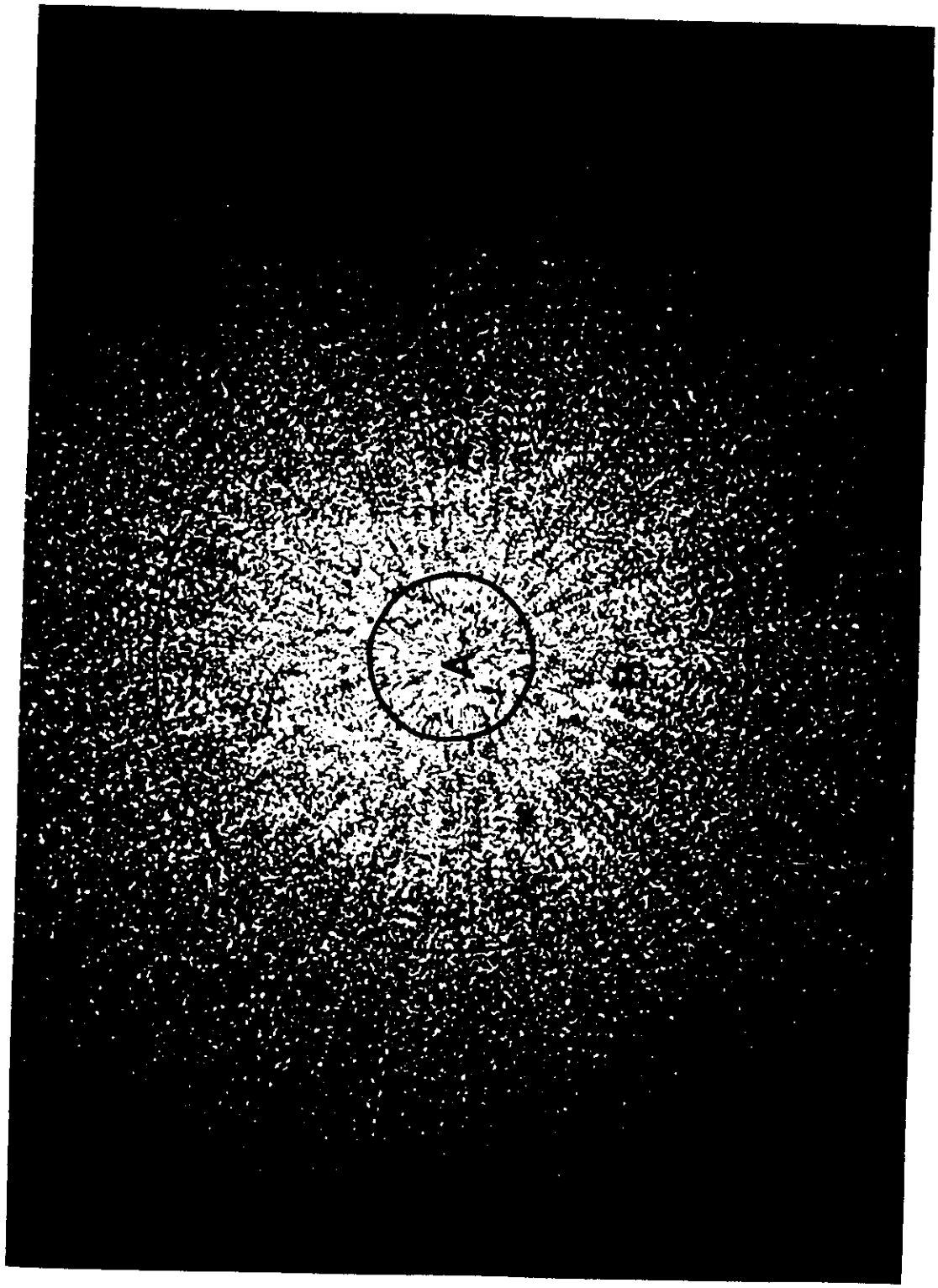
Measuring method	Number of detectors	Boiling	Translation
Autocorrelation method	1	O	O
Cross-correlation method	2	X	O
Spatial filtering method	1	X	O
Zero-crossing method	1		
circular aperture		O	O
directional aperture		X	O

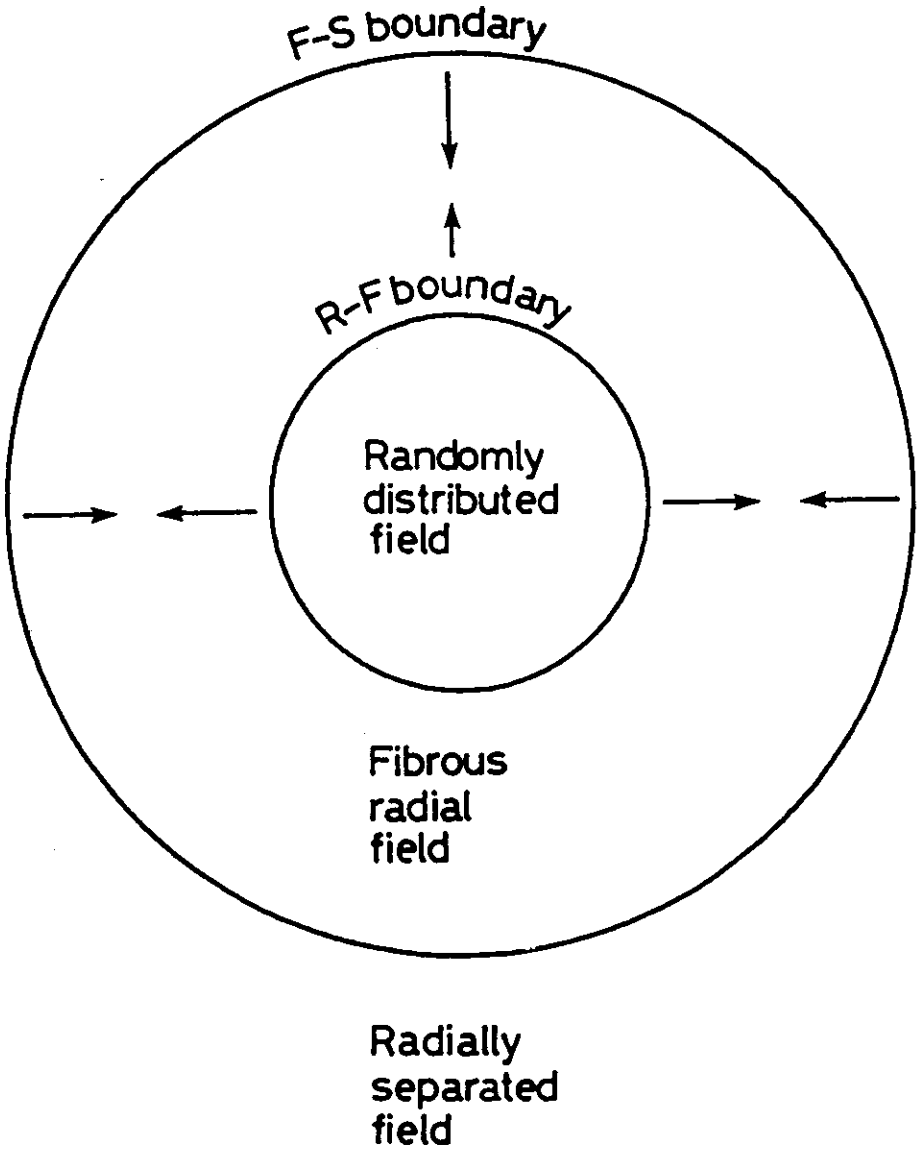
White light . polychromatic light

speckle

Image field speckle : Color separation

Diffraction field speckle : Fibrous structure




F-S boundary
R-F boundary
Randomly distributed field
Fibrous radial field
Radially separated field

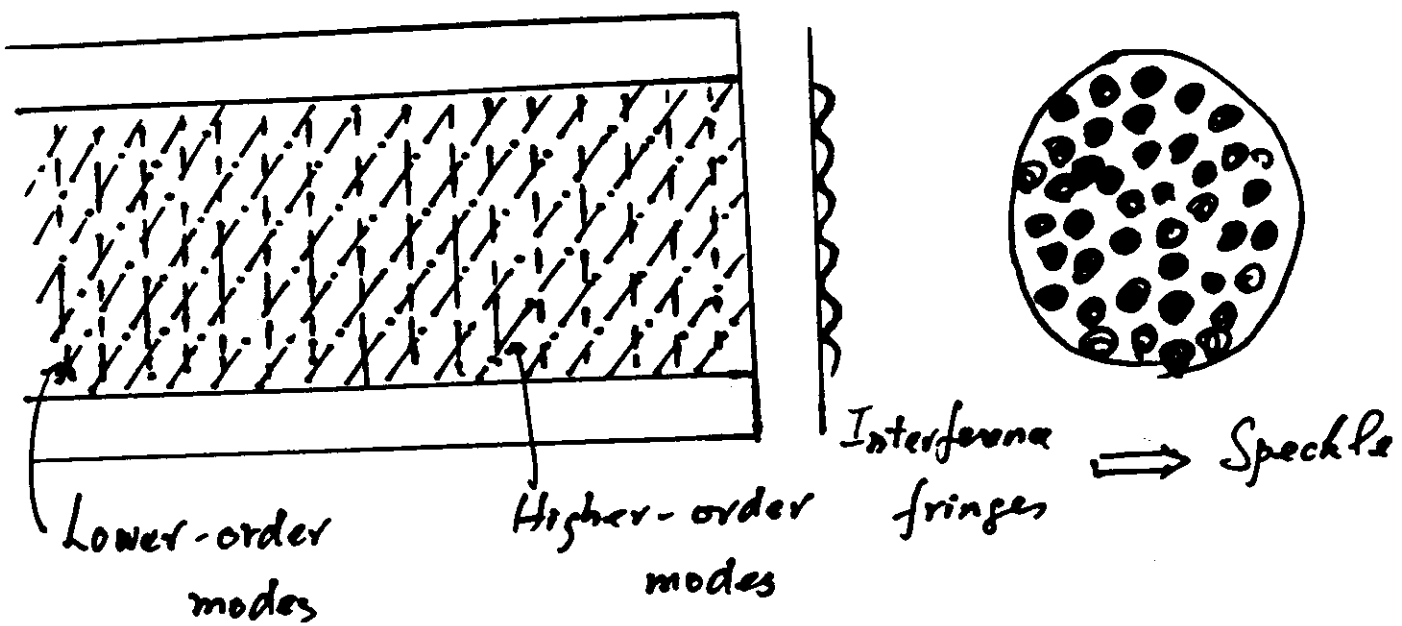
Fiber speckle

Modal noise

Fiber sensor

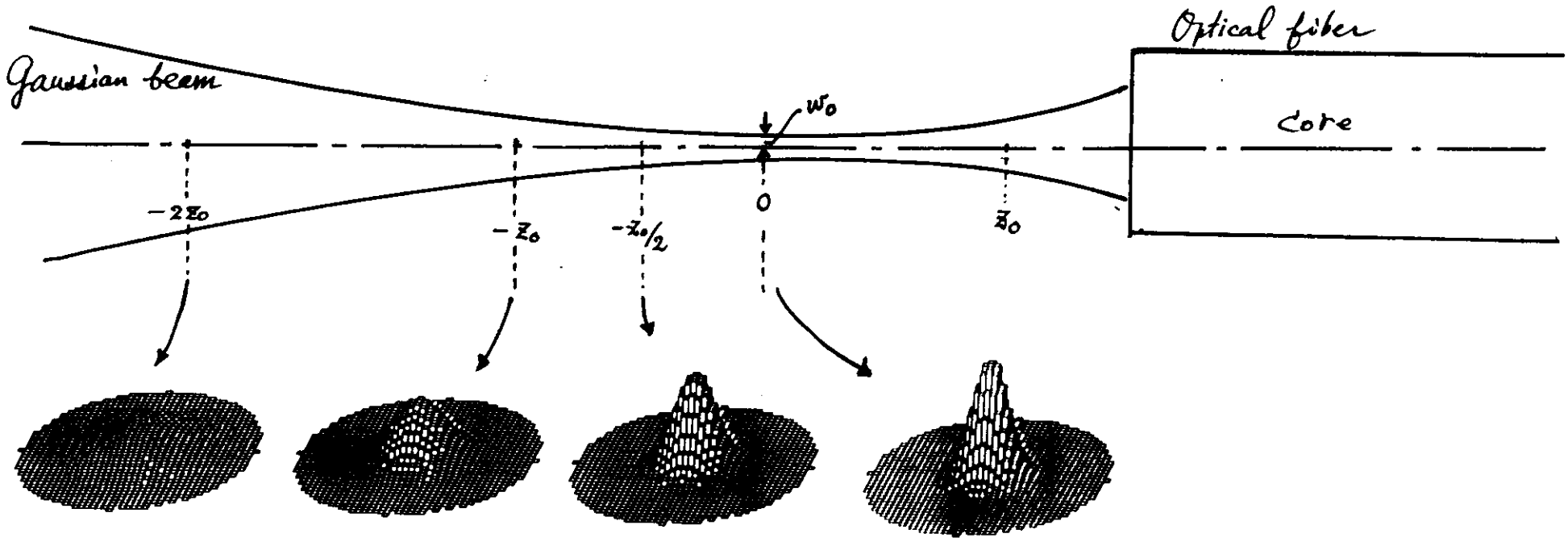
Modal noise ⟹ Fiber speckle

Interference phenomena of fiber modes



Causes of fiber speckle

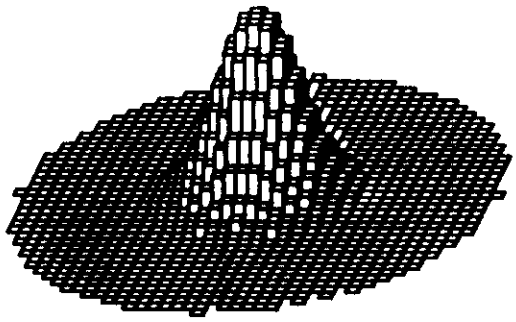
1. High coherence properties of the source (Laser)
2. Selectivity of modes
3. Small numbers of modes
4. Low mode dispersion



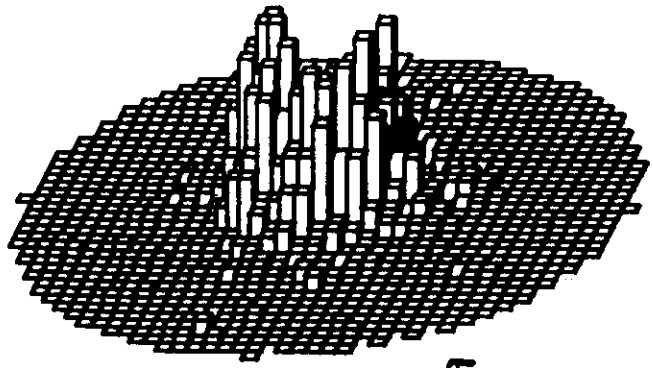
$$z_0 = \frac{\pi w_0^2}{\lambda}$$

Focusing misalignment

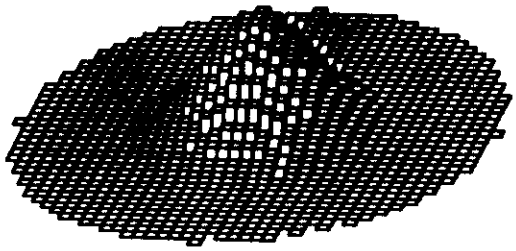
$\sqrt{\langle \Delta\theta^2 \rangle} = \begin{cases} 0.01 & \text{(inside)} \\ 0.05 & \text{(outside)} \end{cases}$



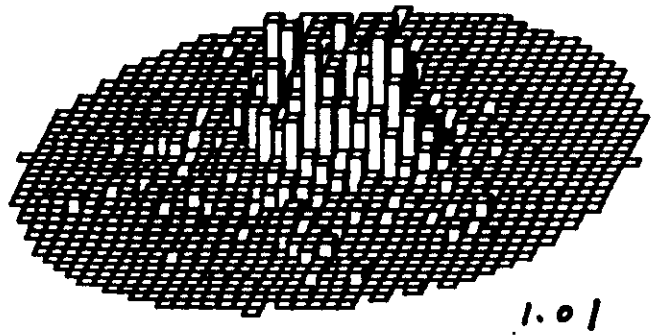
$\Delta z / z_0 = 0.5$



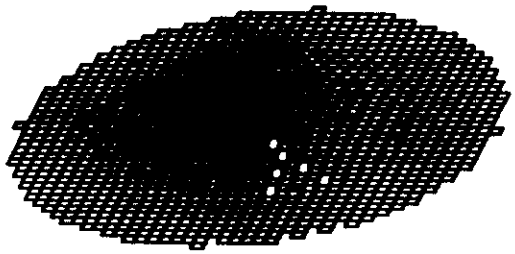
$\sigma_y / \sigma_x = 1.03$



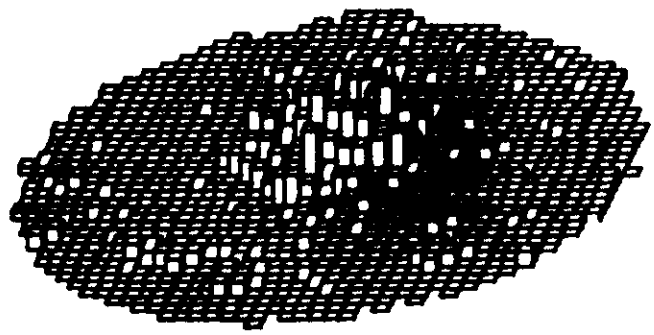
1.0



1.01



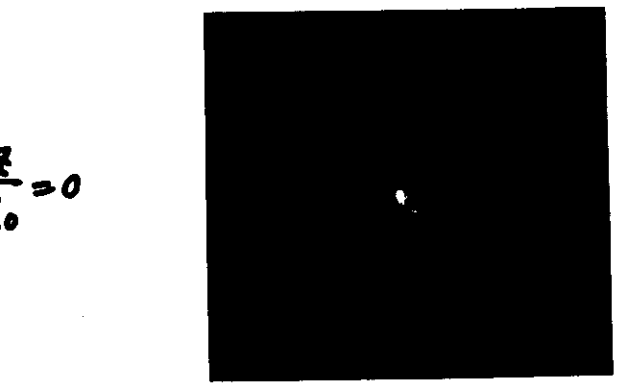
2.0



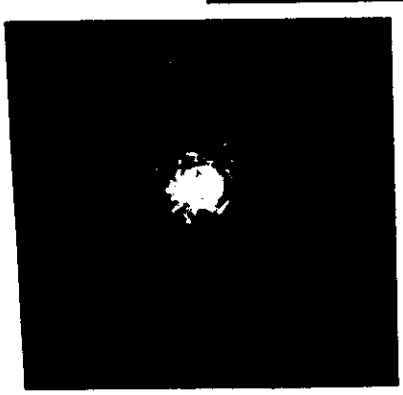
1.01

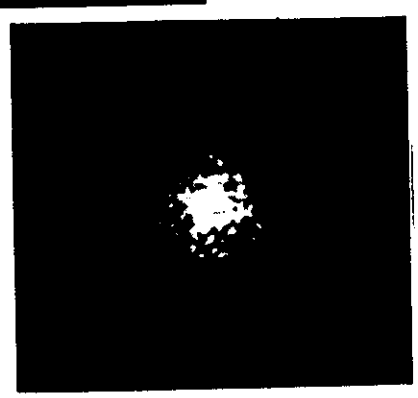
Focusing misalignment

$\frac{\Delta z}{z_0} = 0$



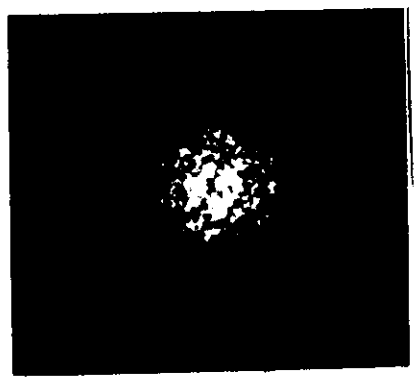
-0.22





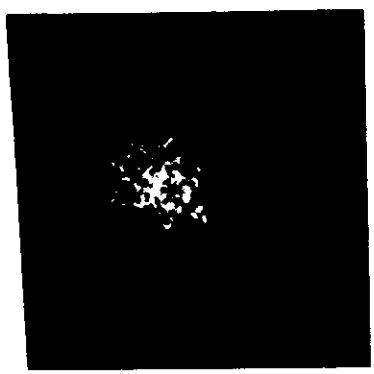
+0.22

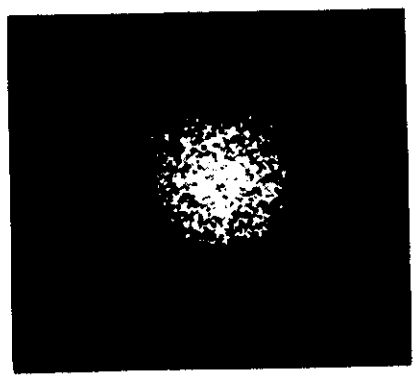
-0.45



+0.45

-0.67

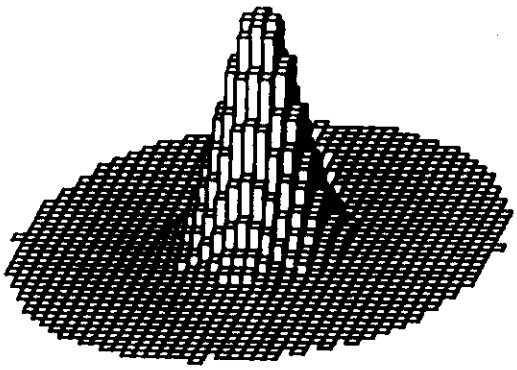




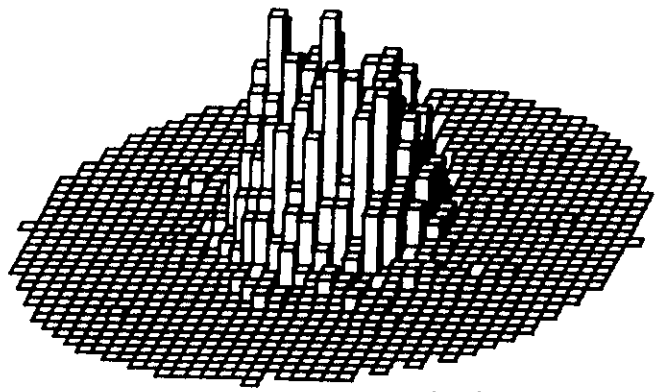
+0.67

Axial misalignment

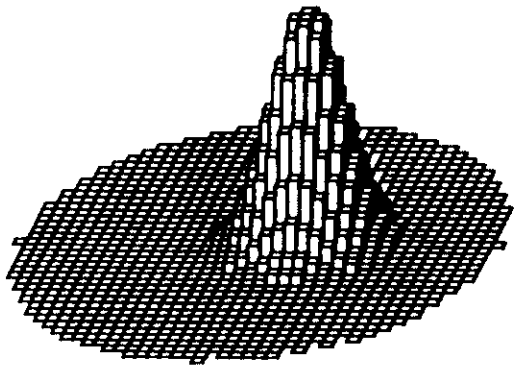
inhomogeneous : $\sqrt{\langle \Delta\theta^2 \rangle} = \begin{cases} 0.01 & \text{(inside)} \\ 0.05 & \text{(outside)} \end{cases}$



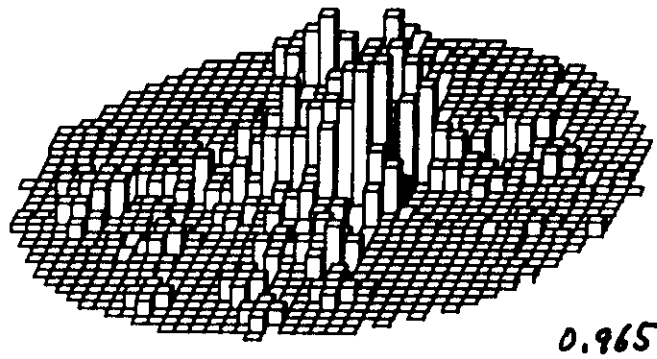
$\frac{\Delta a}{a} = 0.0$



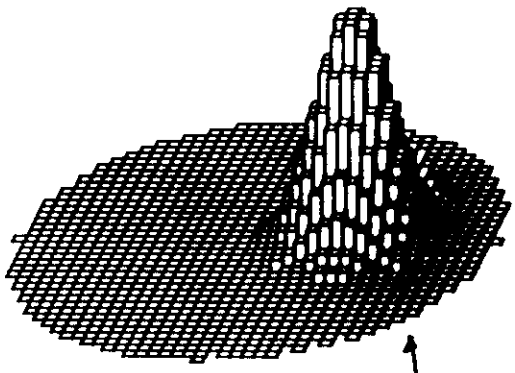
$\sigma_{\parallel}/\sigma_{\perp} = 0.988$



0.2

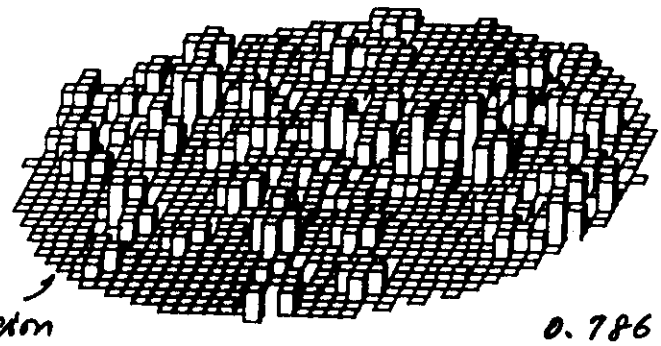


0.965



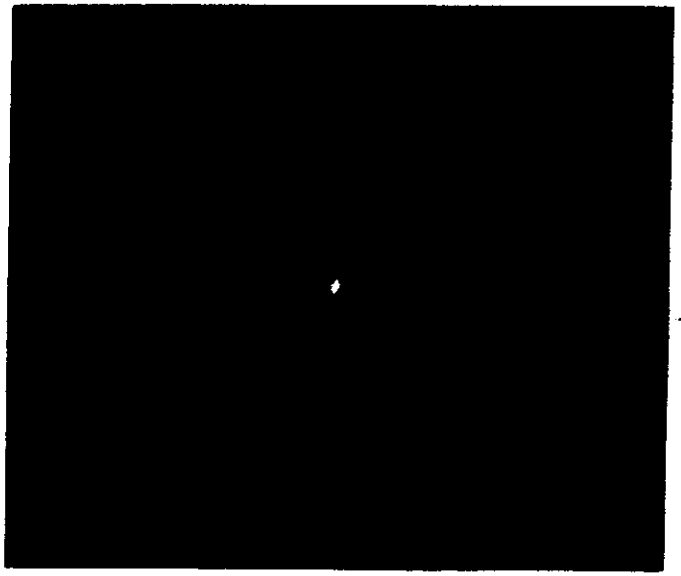
0.4

core region

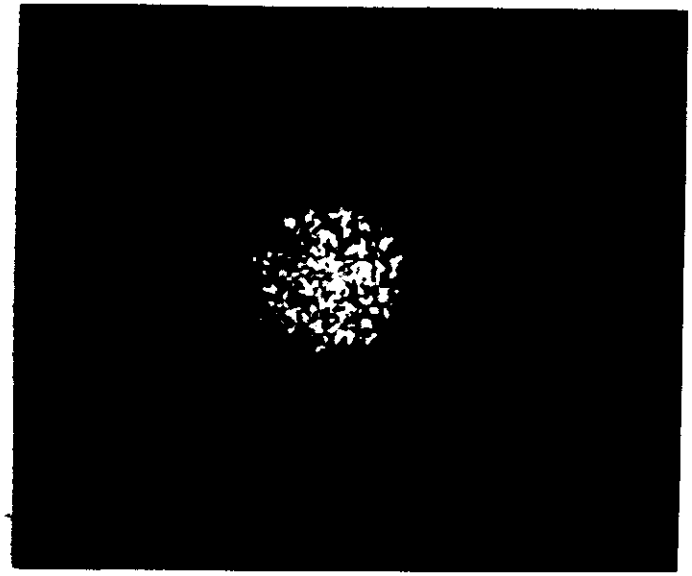


0.786

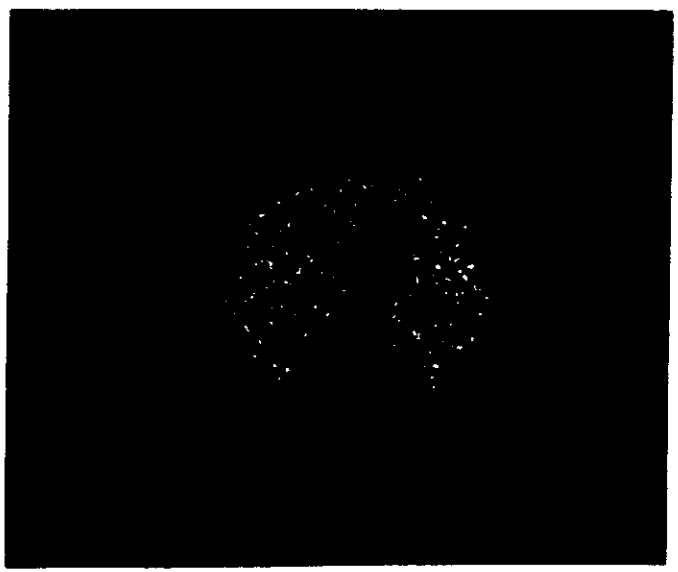
Axial misalignment



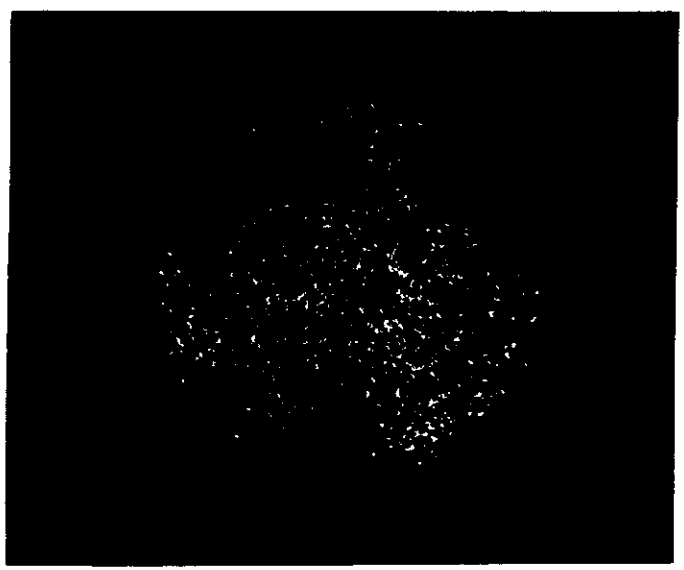
$\Delta a/a = 0$



0.25



0.50



0.75

Bio-speckles

La er speckles produced from living objects

⟹ "Bio-speckles"

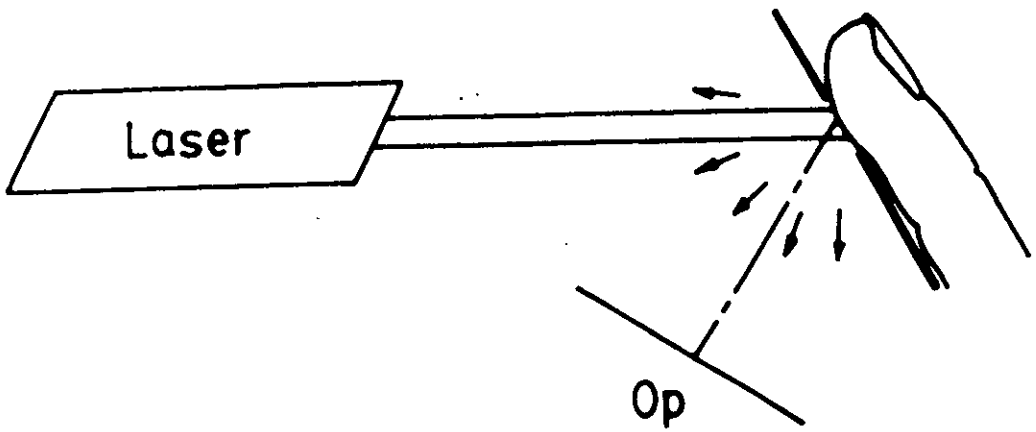
Ti e-varying properties of bio-speckles

⟹ Physiological movements of living objects

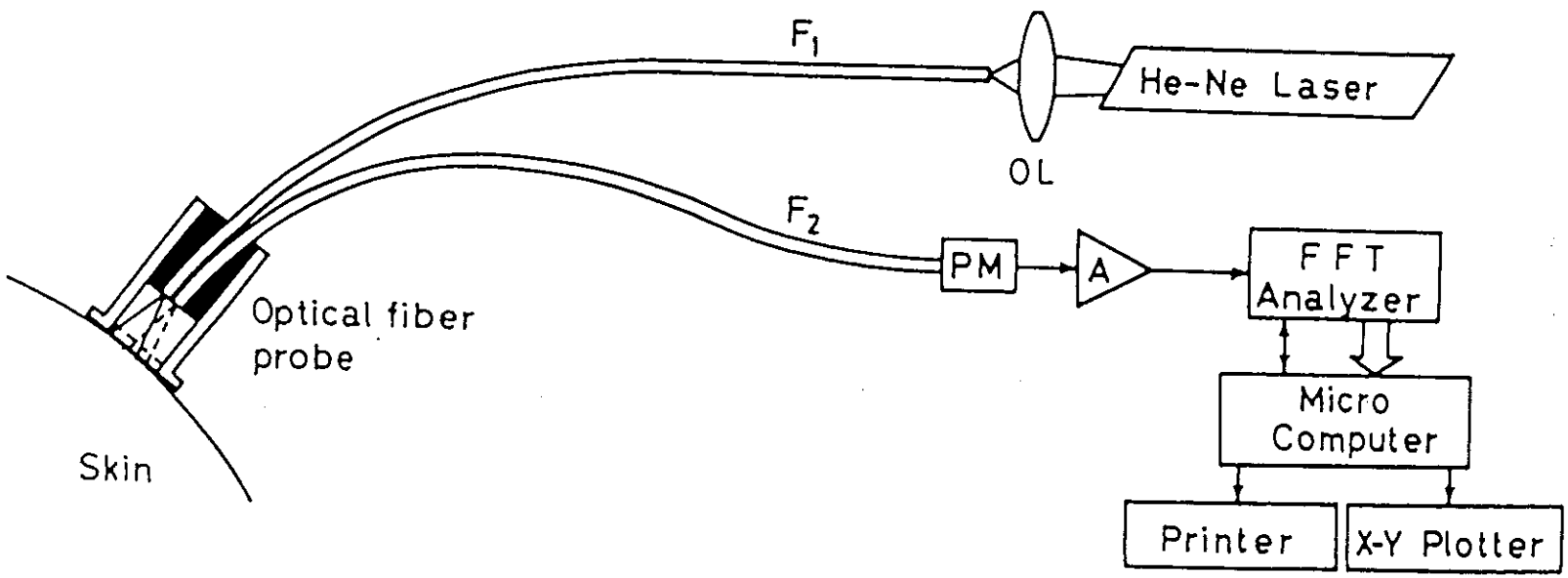
Sp ctral and correlation properties of bio-speckles

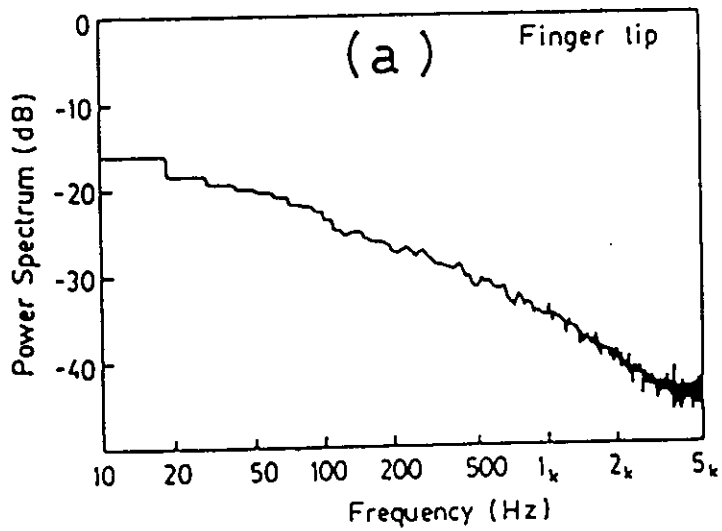
from
- skin surface
- gastric mucous membrane ← Stomach surface
- ocular fundus

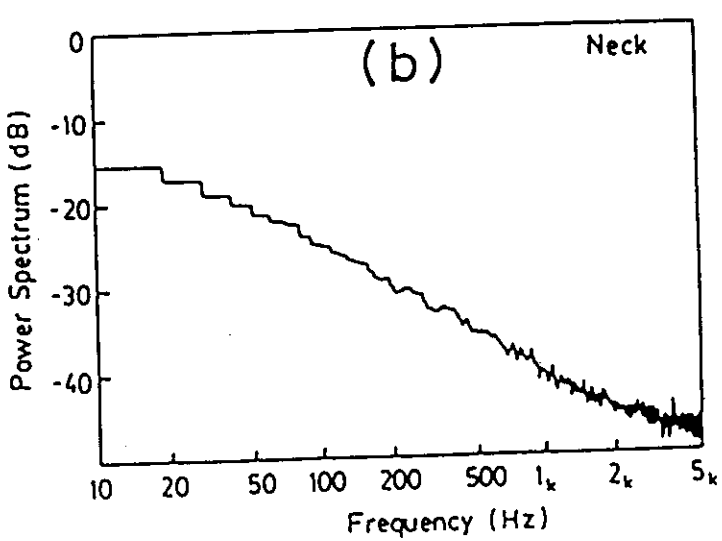
⟹ Measurements of blood flow

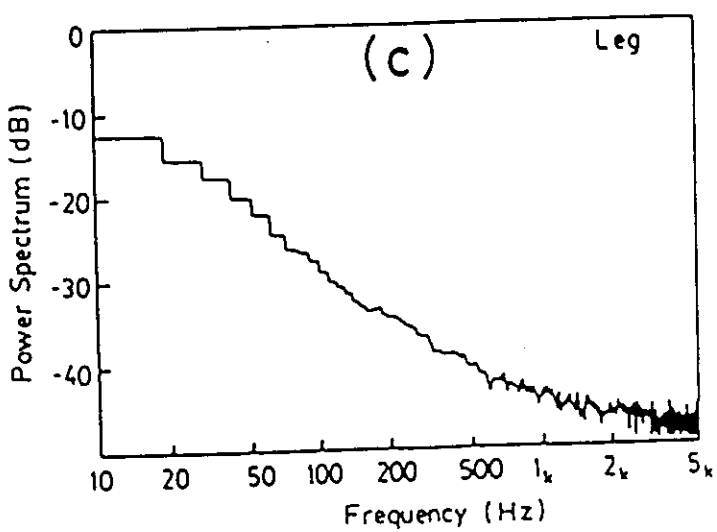


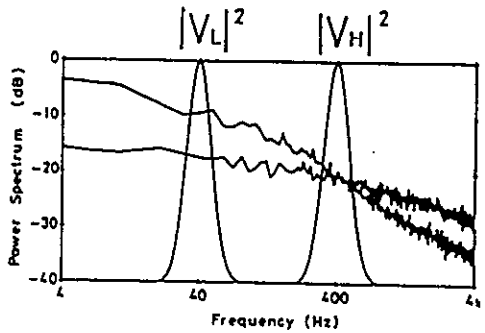
(a) (b) (c)


F1
He-Ne Laser
OL
F2
PM
A
F F T
Analyzer
Optical fiber
probe
Micro
Computer
Skin
Printer
X-Y Plotter

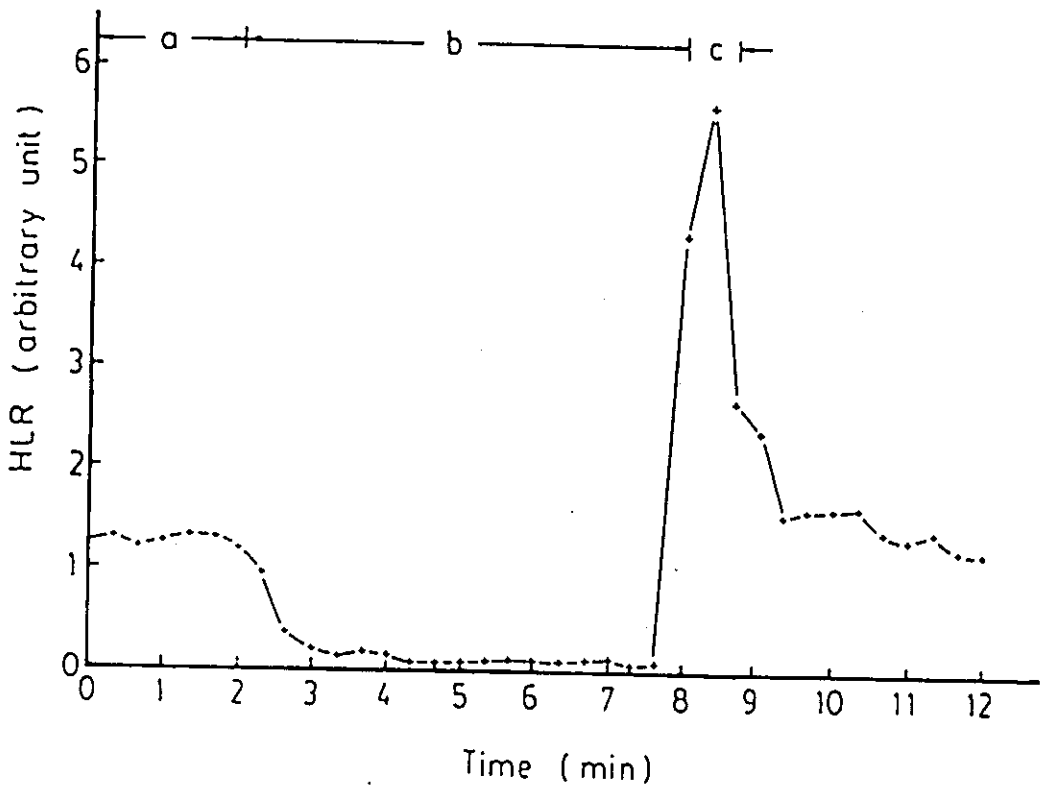

(a)
Finger tip
Power Spectrum (dB)
0
-10
-20
-30
-40
10
20
50
100
200
500
1k
2k
5k
Frequency (Hz)


(b)
Neck
Power Spectrum (dB)
0
-10
-20
-30
-40
10
20
50
100
200
500
1k
2k
5k
Frequency (Hz)

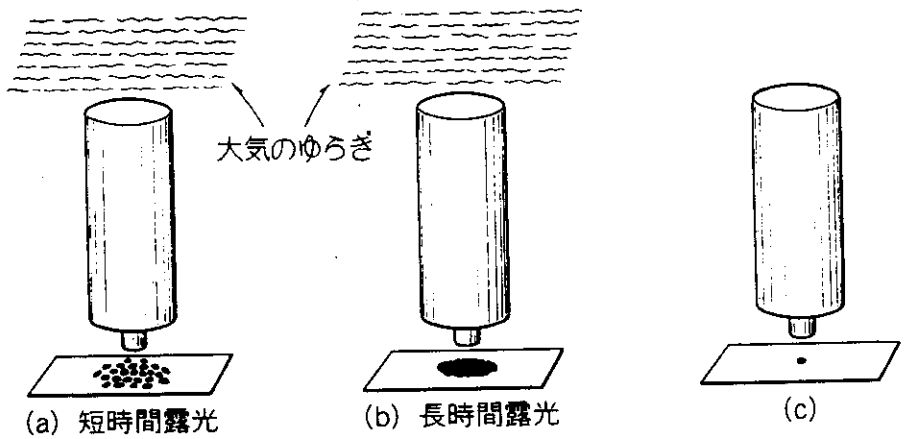

(c)
Leg
Power Spectrum (dB)
0
-10
-20
-30
-40
10
20
50
100
200
500
1k
2k
5k
Frequency (Hz)



$$HLR = \frac{|V_H|^2}{|V_L|^2}$$



Atmospheric turbulence

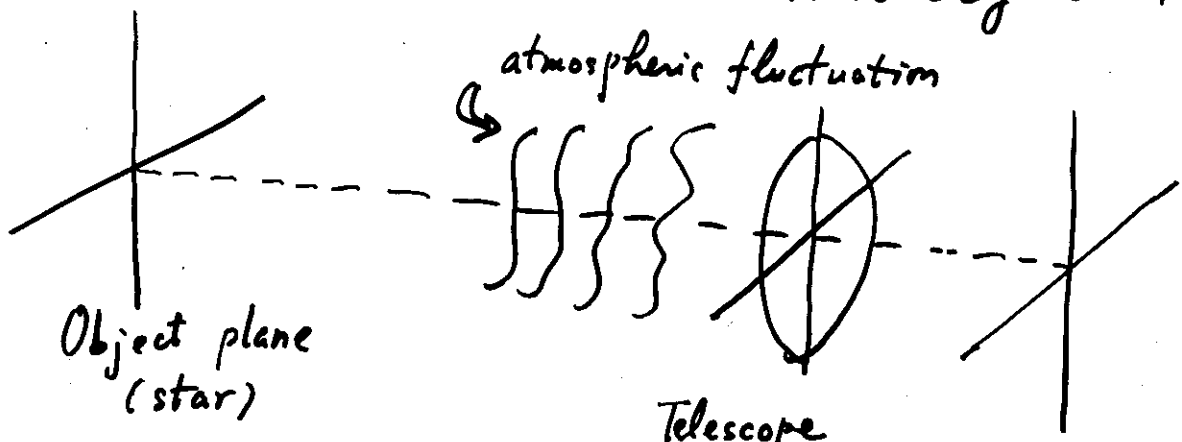


Short-exposure Long-exposure

Star speckles taken with the short time exposure

Stellar Speckle Interferometry

A. Labeyrie (France)



$i_o(x,y)$

⇓ Fourier transform

$I_o(\nu,\mu)$

$s(x,y)$ point spread

⇓ F.T.

$\tau(\nu,\mu)$ Transfer function

$i_i(x,y)$

⇓ F.T.

$I_i(\nu,\mu)$

One step many photos $\quad i_i(x,y) = i_o(x,y) \otimes s(x,y)$: $\otimes$ convolution integral

⇓ Fourier transform (optically)

Second step superposition $\quad I_i(\nu,\mu) = I_o(\nu,\mu)\,\tau(\nu,\mu)$

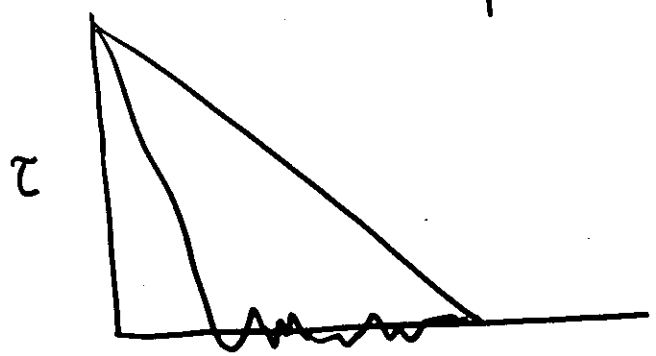
⇓ intensity recording

$$|I_i(\nu,\mu)|^2 = |I_o(\nu,\mu)|^2 \cdot |\tau(\nu,\mu)|^2$$

⇓ averaging

$$\langle |I_i(\nu,\mu)|^2 \rangle = \langle |\tau(\nu,\mu)|^2 \rangle\, |I_o(\nu,\mu)|^2$$

Short exposure



Long exposure

Stellar speckle interferometry