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Application of High-Precision Measurements Techniques for *in situ* Characterization of Optical Components under LIGO II Conditions

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Currently:

3 year (1999-2002) NSF-supported UF/IAP collaborative project "Methods and Instruments for High-Precision Characterization of LIGO Optical Components"

LIGO-G010324-00-Z
Hanford, 2001

Proposed Research

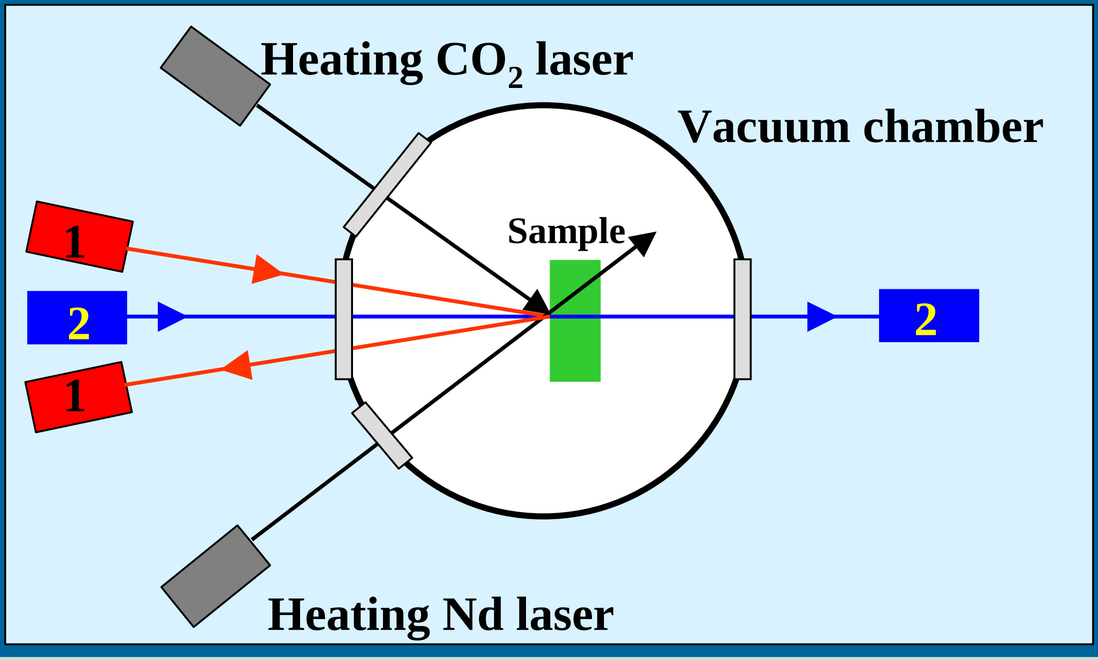
- ♦ **White-light phase-modulated interferometer (WLPMI) for remote control**
- ♦ **Nonlinear Hartmann sensor (NHS) and phase interferometric technique (PIT) for wave front measurement**

Will be used for remote *in situ* monitoring of weak distortions emerging in optical properties of interferometer components under heating similarly to what is expected in LIGO II core optics

Using vacuum environment and auxiliary laser heating we will induce controllable large-scale and small-scale surface and bulk heating effects and characterize them by constructing optical thickness and wave-front inclination maps

With these techniques, a precision higher than $\lambda/1000$ compatible with the LIGO II requirements is expected to be demonstrated at *in situ* experiments

Modeling Effects of High-Power Laser Radiation with Low Power Laser



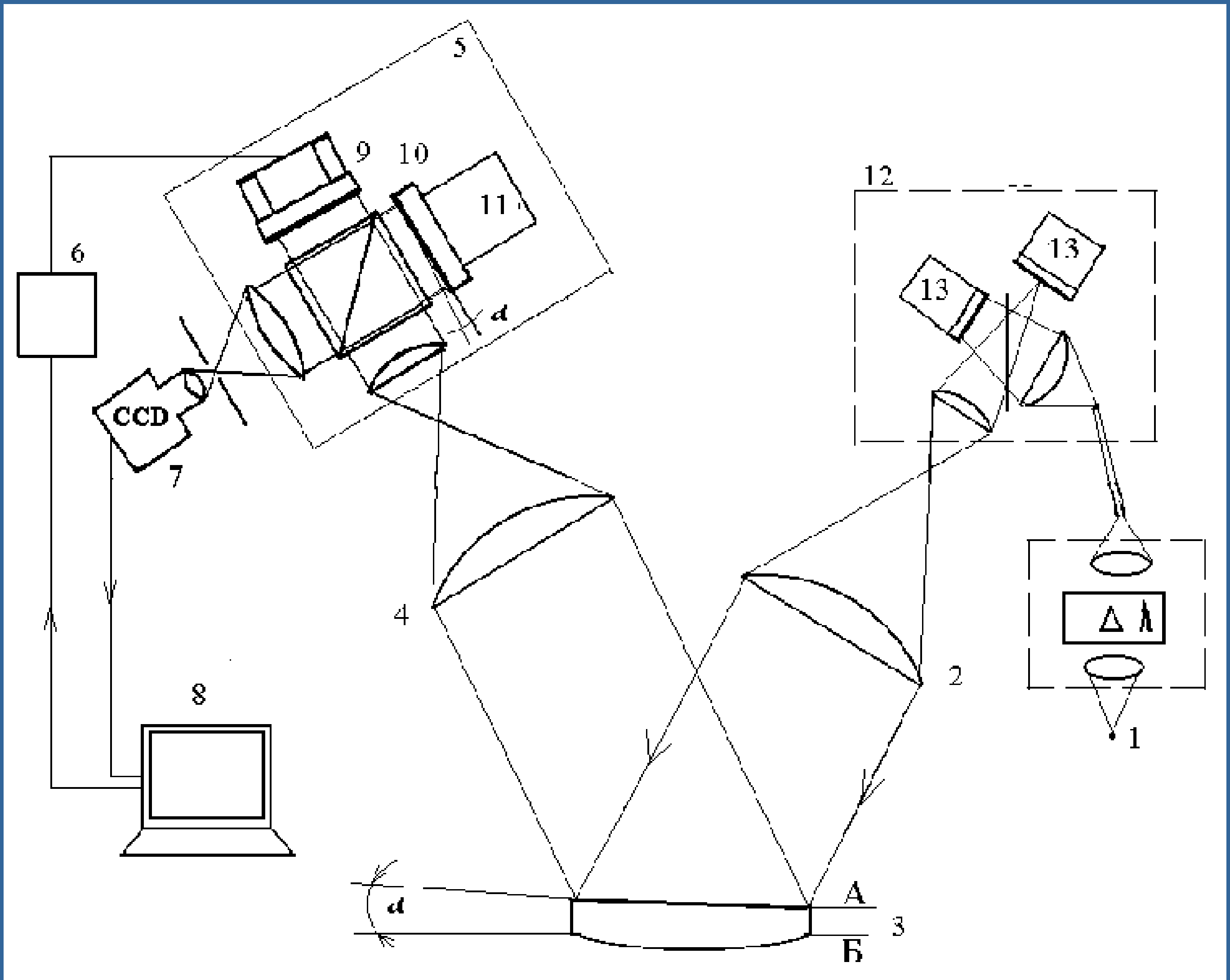
1 - **WLPMI**
2 - **NHS and PIT**

- Optical glass bulk heating by the fundamental or second harmonic of Nd:YAG laser at a power of 10-20 W
- Surface heating with the use of a CO_2 laser at power of several Watts
- Inducing contamination of a small region (characteristic size of 20-100 micron) on the optical element's surface and focusing of low-power laser radiation (<100 mW) on it

Novel White Light *In Situ* Measurement Interferometer (WLISMI)

Standard interferometers	Proposed interferometers
Measurement of optical length of air spacing between two surfaces. In profilometers one of them is a sample surface, and the other is a reference surface. The problem of precise measurement oh phase in the interferogram is solved by phase modulation according to a known time law.	The proposed method relies on measurements of the phase of interferogram of radiation reflected **from two surfaces of one sample** under study. The precise phase measurements are ensured by the **modulation** of the probing radiation **spectrum**. The method provides a two-dimensional pattern of a sample's **optical thickness distribution** simultaneously over the whole aperture. The method is applicable to **remote testing** of optical elements with flat, spherical and cylindrical surfaces, and also with a wedge between them.

White Light *In Situ* Measurement Interferometer. Experimental setup



1 - light source;

2 - objective;

3 - sample;

4 - ocular;

5 - measurement interferometer;

6 - unit for synchronization and control;

7 - CCD camera;

8 - PC computer;

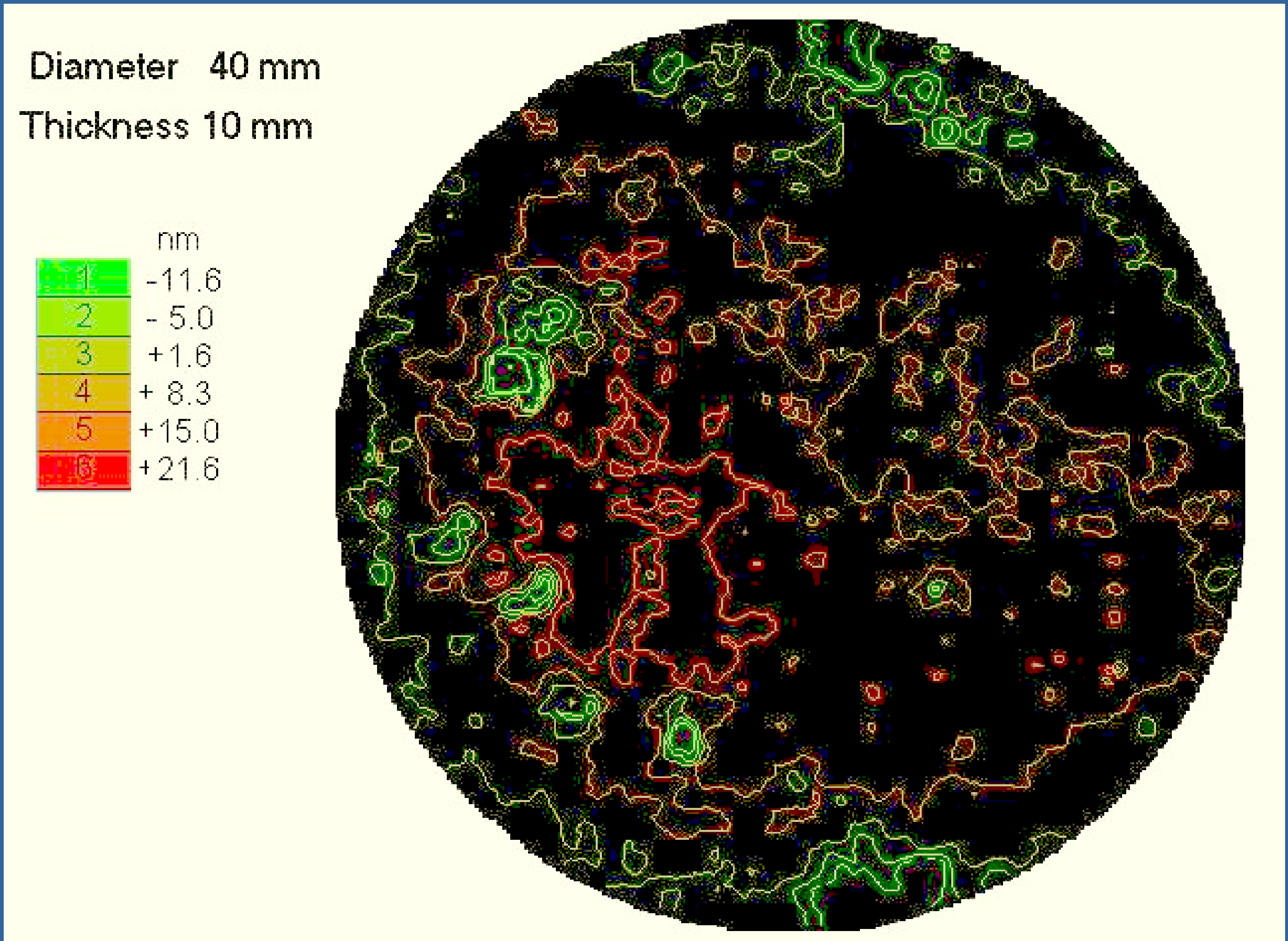
9 - modulating mirror;

10 - adjusting mirror;

11, 13 - motors;

12 - wave front shaper

White Light *In Situ* Measurement Interferometer. First phase map



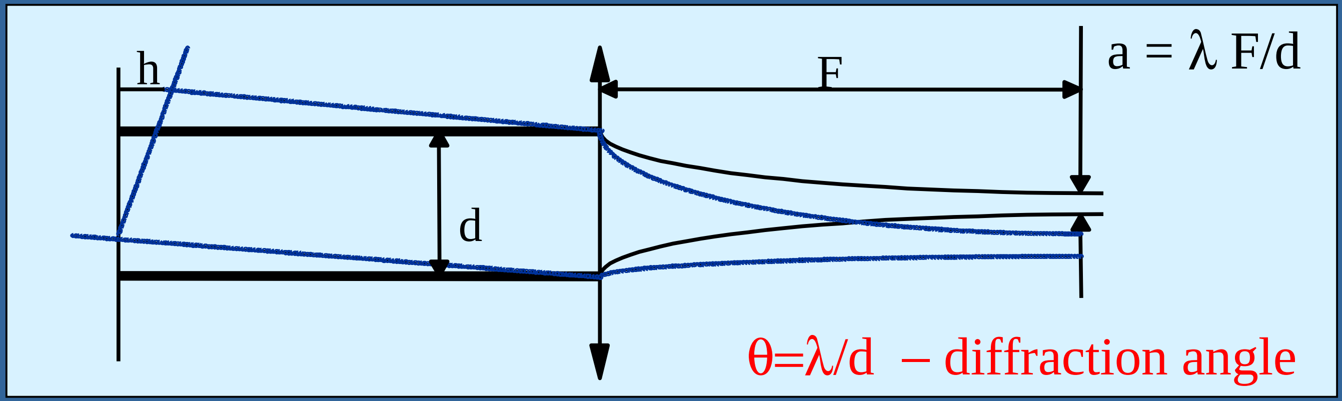
Workplan

- Testing of main units of WLISMI in prototypes with a 40 mm aperture
- Development and creation of a test system which will include the vacuum chamber and elements for heating of test samples
- Creation of a prototype WLISMI with an aperture of 100 mm
- Conducting tests, calibration and, based on the results of the tests, improvement of WLISMI
- Integration of WLISMI with the vacuum chamber

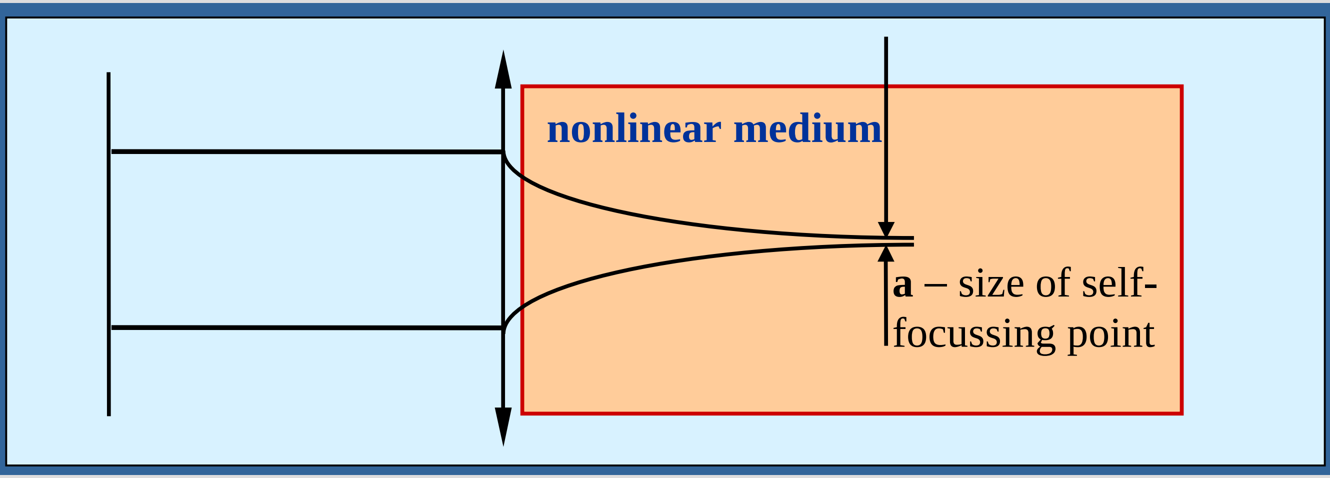
Nonlinear Hartmann Sensor

- The limiting capability of one channel Hartman sensors is imposed by diffraction. It is possible to partly weaken the negative influence of the diffraction by transmitting a beam through a nonlinear cubic medium, i.e. using the effect of self-focusing
- Under certain conditions, a "self-focusing point" can be observed in the far field of the beam, i.e. in the plane of a lens focus
- Since the transverse dimensions of the self-focusing point are smaller than the size of the beam propagating in a linear medium, the accuracy of measurement of the wave front curvature and the beam deviation angle can be improved

NHS: Idea

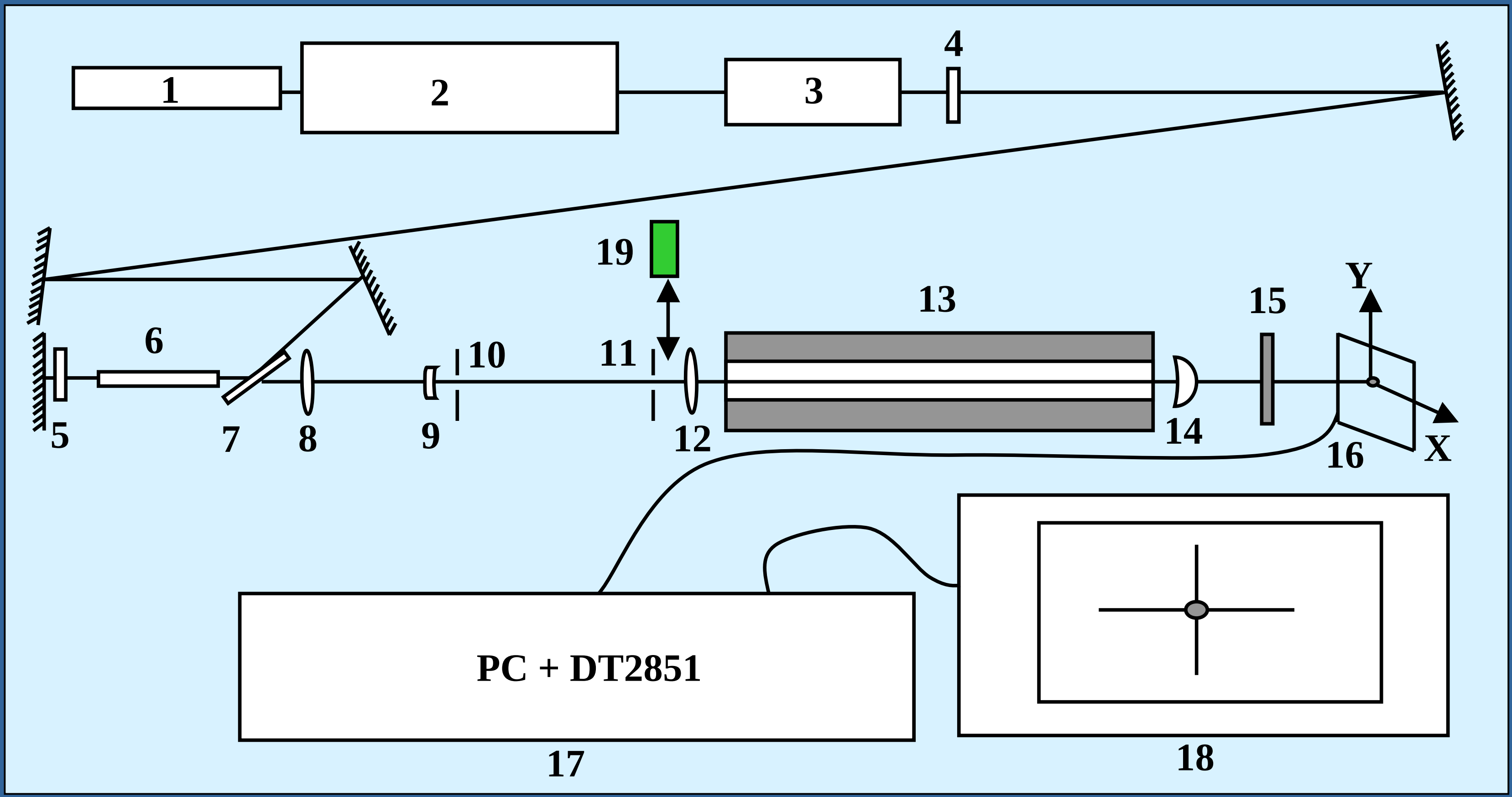


In linear electrodynamics the major limitation to measure wave front deviations angles comes from a finite size of the focal spot $h=\lambda/20...\lambda/50$ is achieved by an accurate measurement of the transverse beam distribution



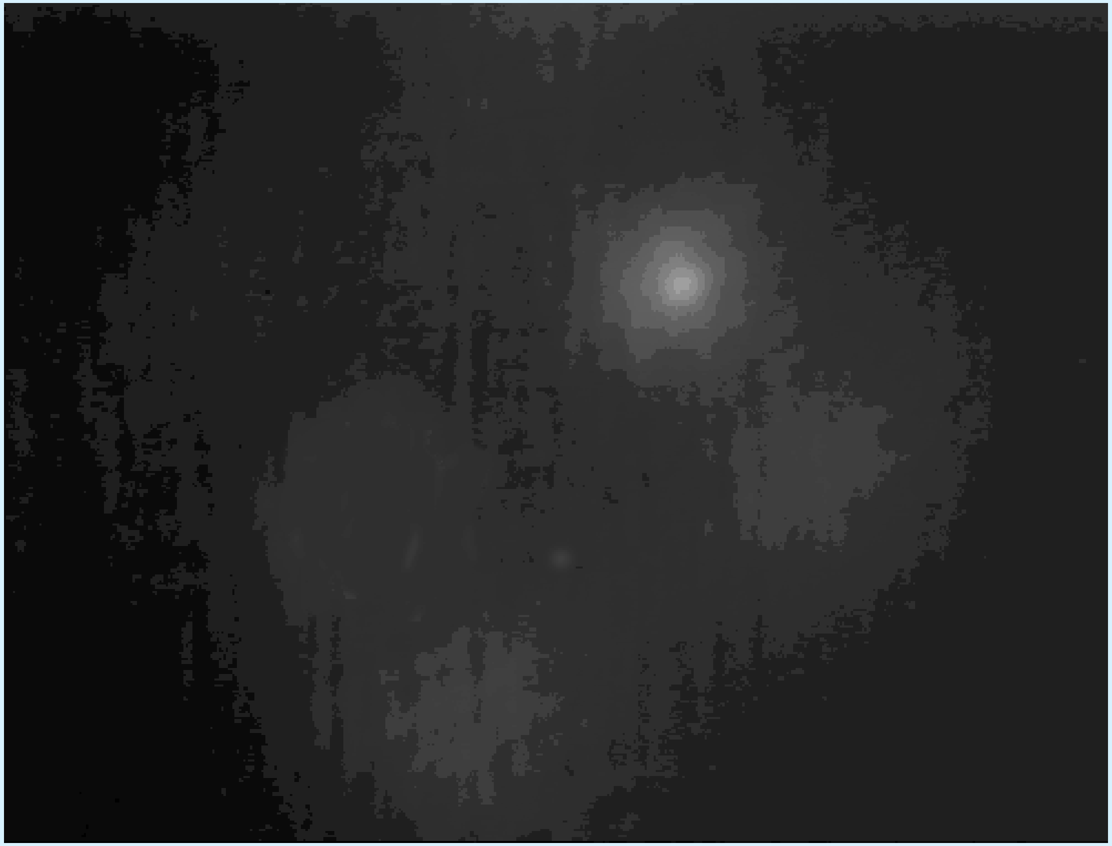
How to get $\lambda/1000$? Use self-focusing to decrease the size of the focal spot.
At $P=P_{critical}$ $a \to 0$ and is determined by nonlinear medium properties

NHS: Experimental Setup with Moving Sample



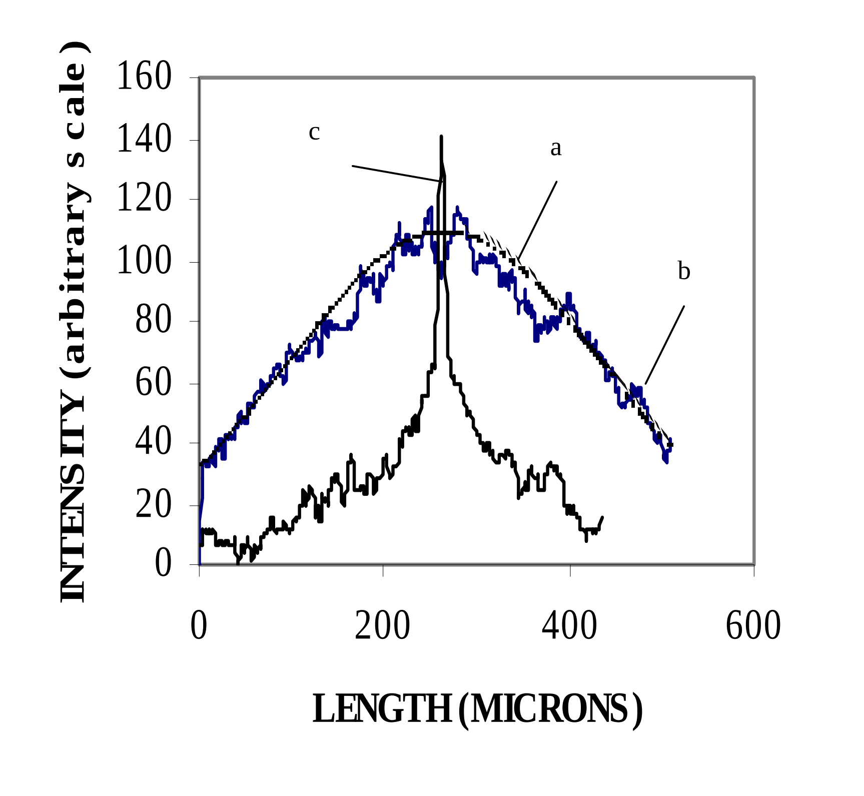
1 – HeNe laser; ***2*** – Nd master oscillator; ***3*** – single pulse selector; ***4*** – λ/2;
5 – λ/4; ***6*** – Nd amplifier; ***7*** – polarizer; ***8, 9, 12, 14*** – lenses; ***10, 11*** – pinholes;
13 – bensen cell (L=40 cm); ***15*** – attenuator; ***16*** – CCD camera;
17 – PC+Frame Grabber; ***18*** – analog monitor; ***19*** – sample.

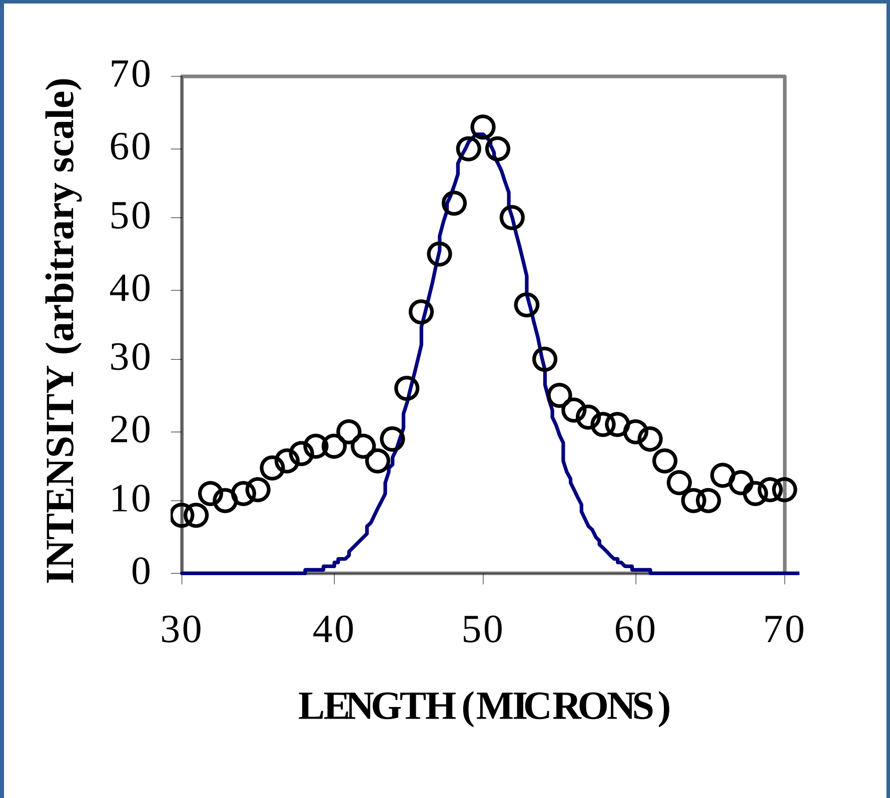
NHS: Self-Focusing Points



difraction limited diameter

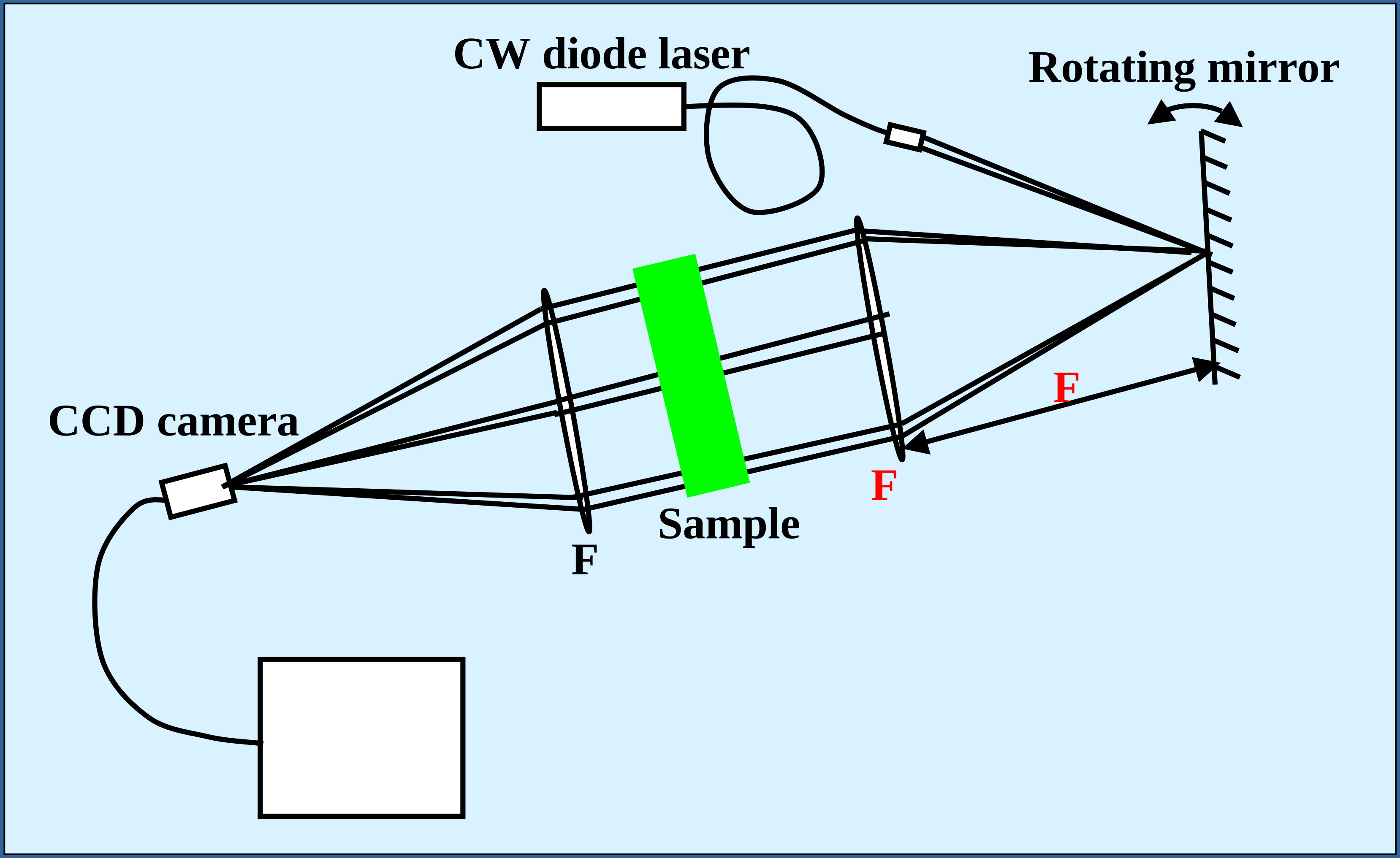
NHS: Results with Moving Sample



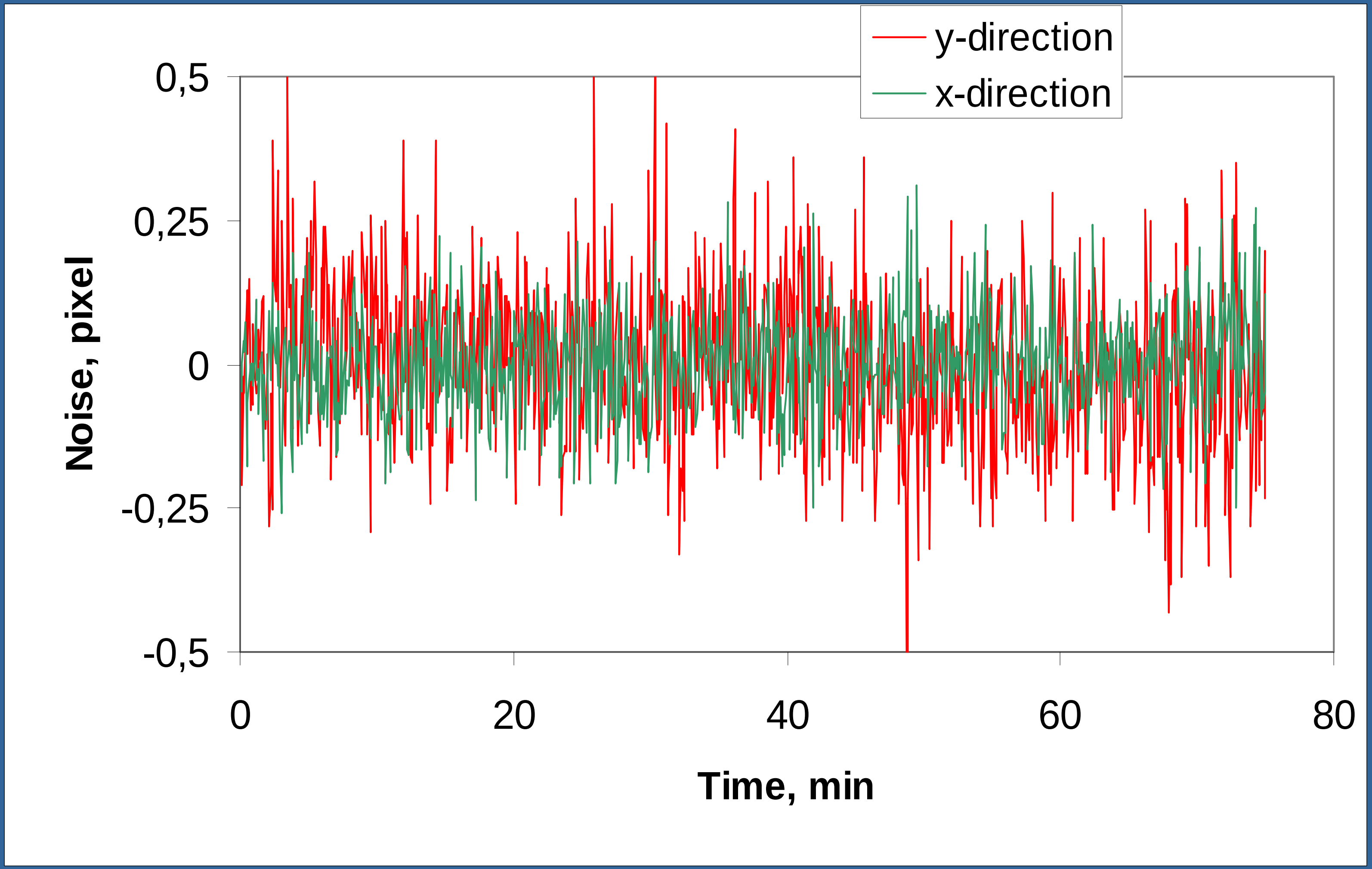


Of all the tested substances, the minimum size of a self-focusing point is in benzene, i.e. 5 μm at the length of a nonlinear cell of 60 cm, which results in the precision of wave front inclination measurements $\lambda/3000$.

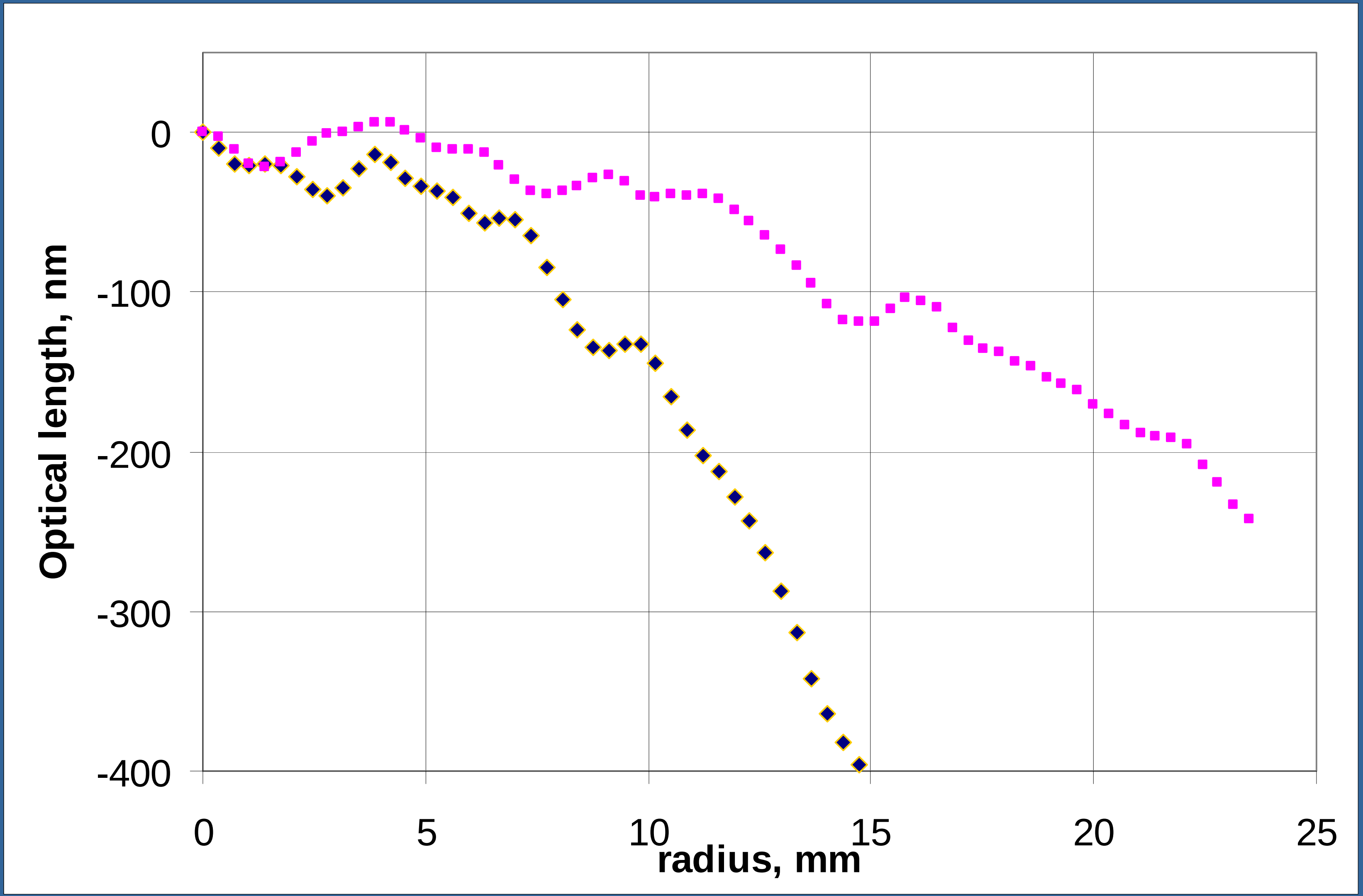
Beam Scanning Technique. Idea.



Beam Scanning Technique. Noise Measurements



Beam Scanning Technique. First Phase Maps



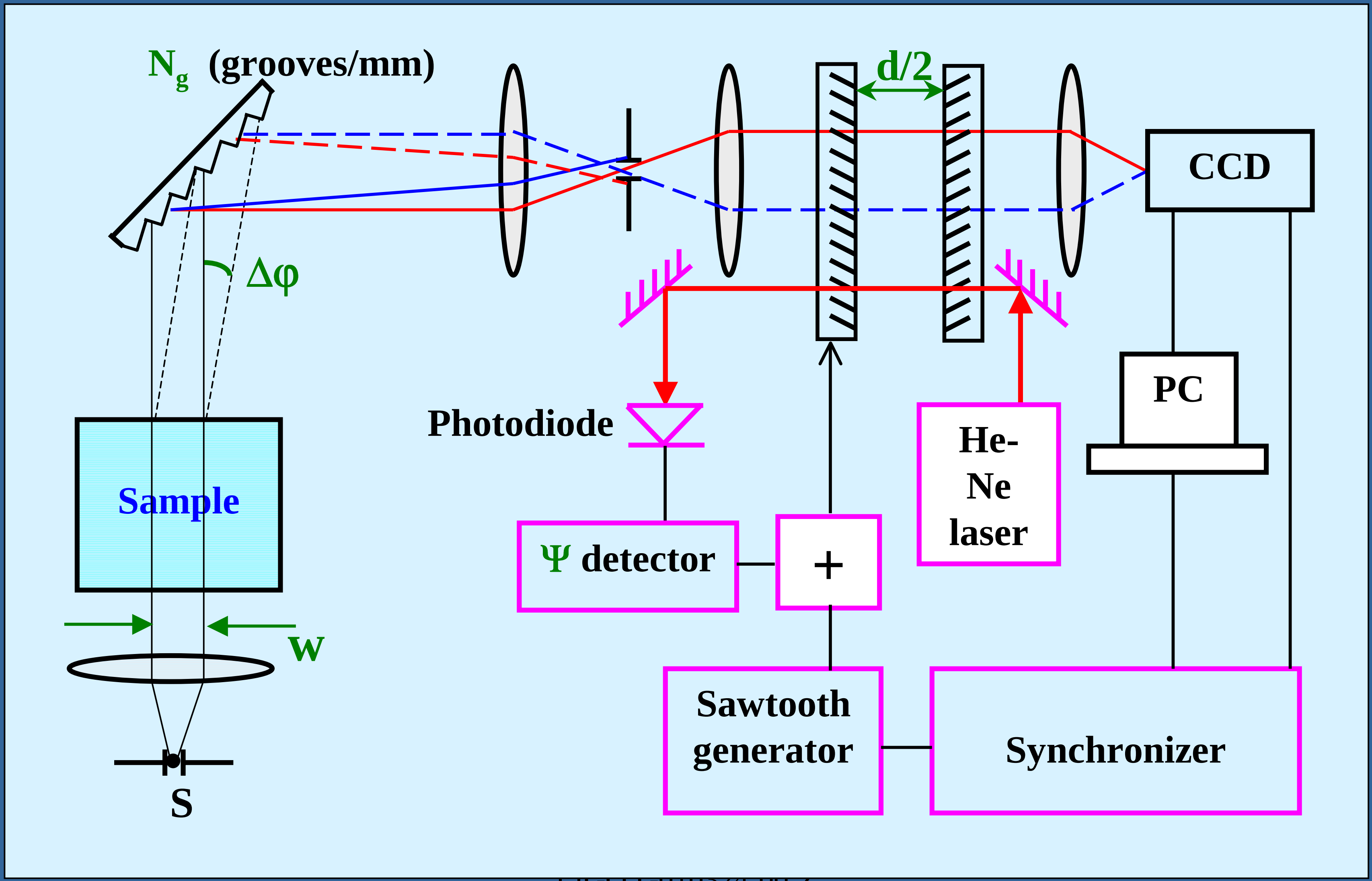
Workplan

- To develop, create and test devices for one-dimensional scanning a beam over a test sample within 5 cm
- To determine experimentally measurement errors introduced by a scanning device both during a single and multiple measurements
- To integrate the NHS with the vacuum chamber and perform various experiments with different heating scheme and optical components

Study of Wave Front Distortion with a Phase Interferometric Technique

- Method is borrowed from solar astronomy
- Spectrometric Doppler measurements of solar photosphere flows were impeded by "spectrum trembling" due to air motion inside the device
- To study the effect of air fluctuations, a method for high-precision measurement of beam angle deviation was proposed

Scheme of the Device

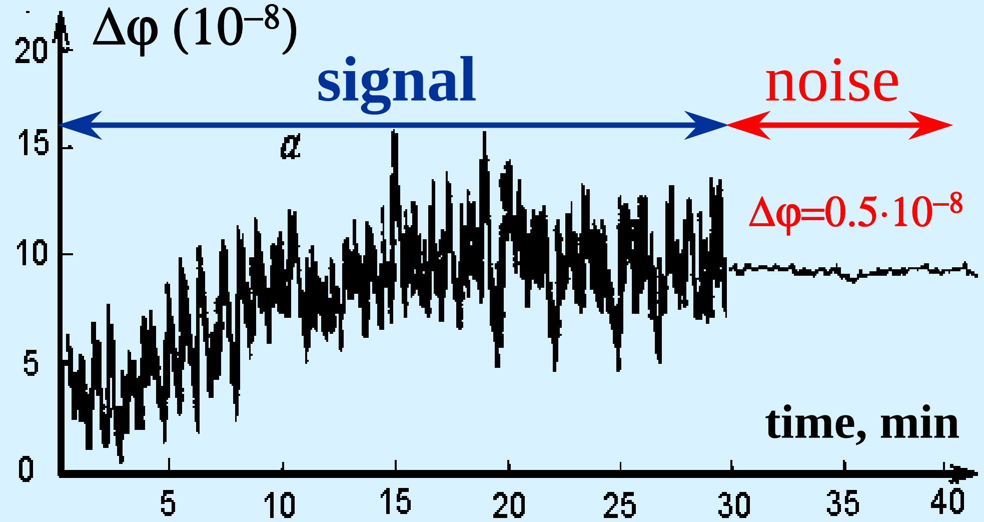


Precision of Measurements

$$\Delta\varphi = \frac{d\varphi}{d\lambda}\Delta\lambda = \frac{\Delta\lambda}{\lambda} \qquad \frac{\Delta\lambda}{\lambda} = \frac{\Delta\Psi}{2\pi}\frac{\lambda}{d}$$

$$\Delta\varphi == \frac{\Delta\Psi}{2\pi}\frac{\lambda}{d}$$

$$d_{\max} = \frac{1}{\delta\lambda_{grating}} = \lambda N_g w$$



$$sag \equiv w\Delta\varphi_{\min} = \frac{\Delta\Psi}{2\pi}\frac{1}{N_g}$$

$$N_g = 1000\,/\,\mathrm{mm}$$

$$\Delta\Psi = 0.5\cdot 10^{-3}\cdot 2\pi$$

$$\frac{\Delta\lambda}{\lambda} = \Delta\varphi = \frac{\lambda}{1000\,w} = 0.5\cdot 10^{-8} = \frac{\Delta d}{d}$$

$$w = 100\mathrm{mm}$$

$$sag = \frac{\lambda}{1000}$$

may be better !

supported by stabilized He-Ne laser

Milestones

- the creation of a vacuum chamber provided with vacuum windows
- carrying out computations to determine optimum heating parameters for modeling LIGO II Core Optics Components
- carrying out computations to define an optimum material of the optical elements for the heating modeling in Core Optics Components
- the assembling of a laser source(s) for heating of the optical element and its integration with the vacuum chamber
- modernization of the NHS and its integration with the vacuum chamber
- construction of the novel WLISMI and its integration with the vacuum chamber
- the design and construction of a setup to implement the phase interferometric technique

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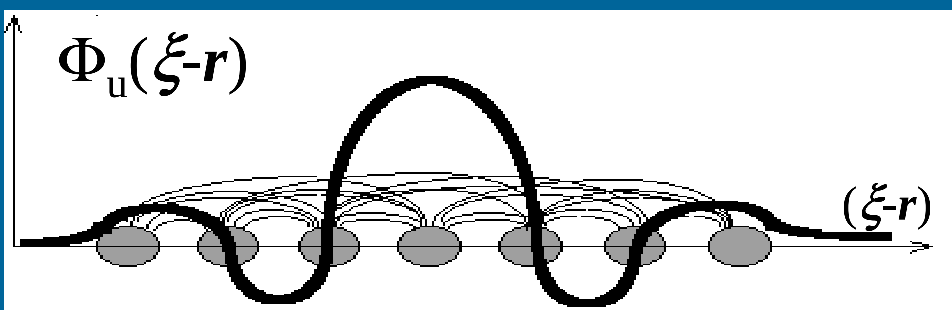
Image Processing and Recognition Using Homogeneous Neuron-Like Networks

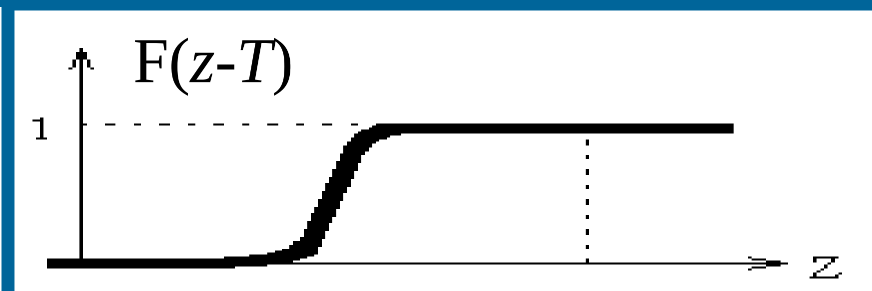
**Vladimir Yakhno, Irene Nuidel,
Alexander Telnykh, Oksana Telnykh,
Alexander Kogan**

LIGO-G010324-00-Z

Basic Model of a Homogeneous Distributed Neuron-Like System

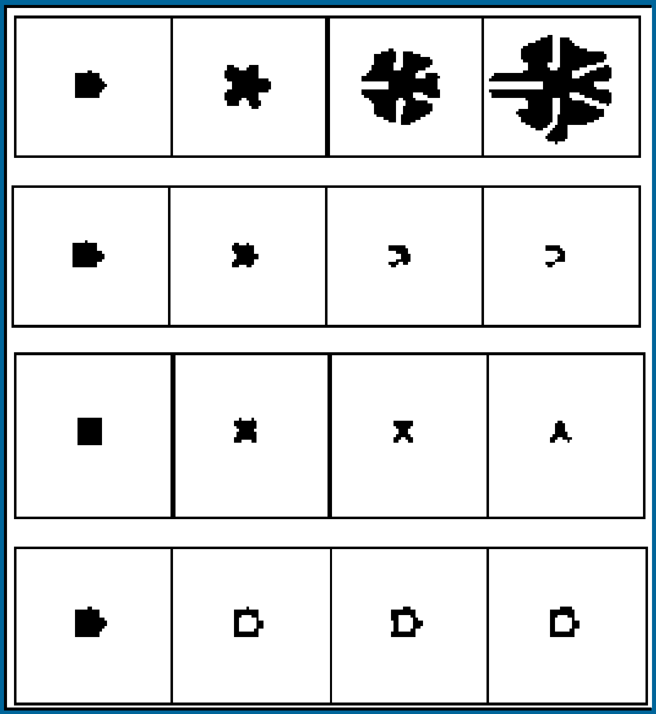
$$\tau_u \, {\partial u}/{\partial t} = -u + F\left[-T + \alpha \int_{-\infty}^{+\infty} \Phi_u\left(\vec{\xi} - \vec{r}\right) \cdot u\left(\vec{\xi}, t\right) \cdot d\vec{\xi} + u_{ex}\left(\vec{r}, t\right) \right]$$

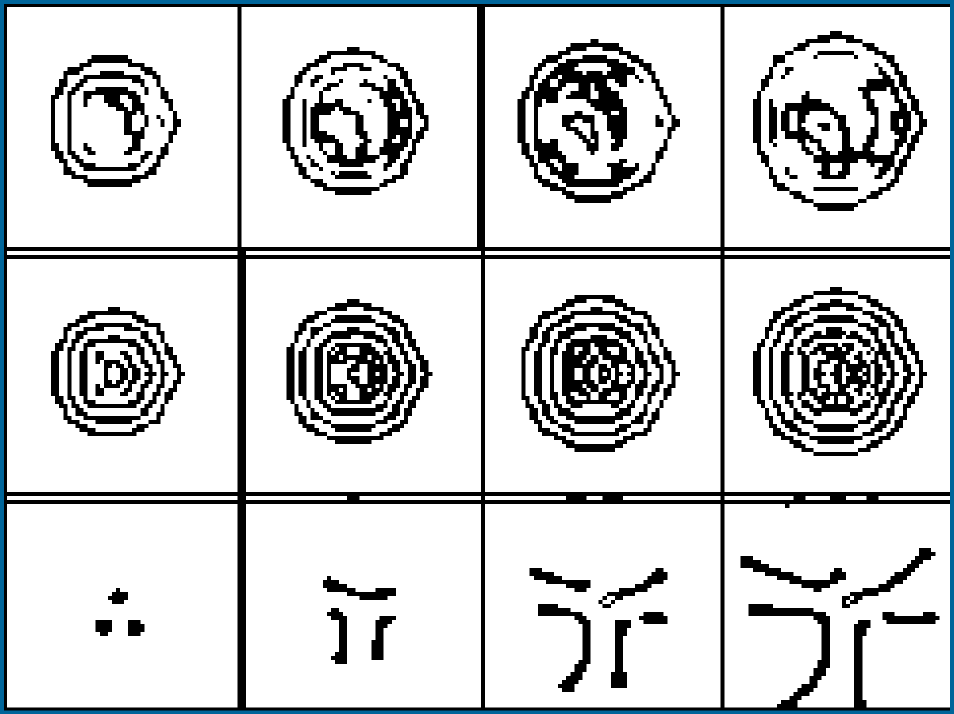




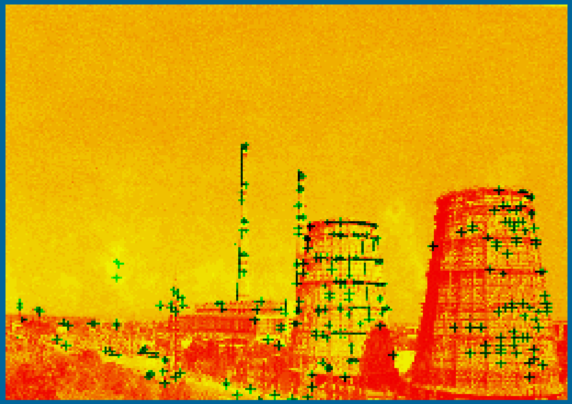
Continuous model of cellular neural/nonlinear networks (CNN)

Modes of Spatial Dynamics in a Distributed Neuron-Like System

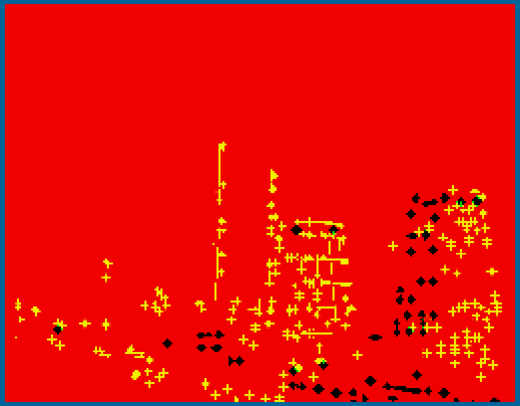




Algorithms for Extraction of Image Features

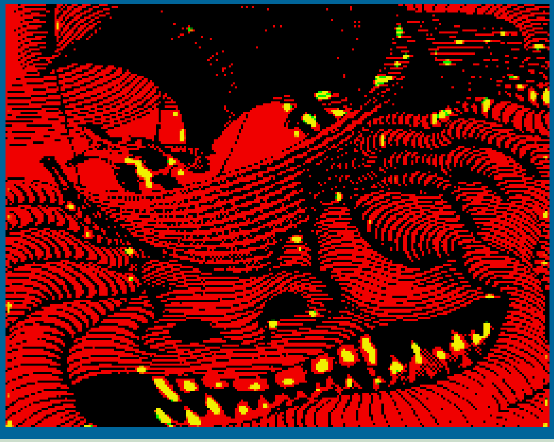


a



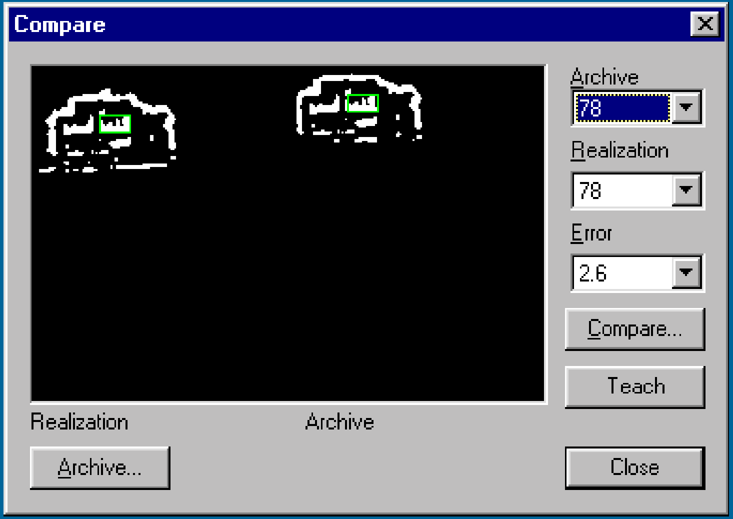
b

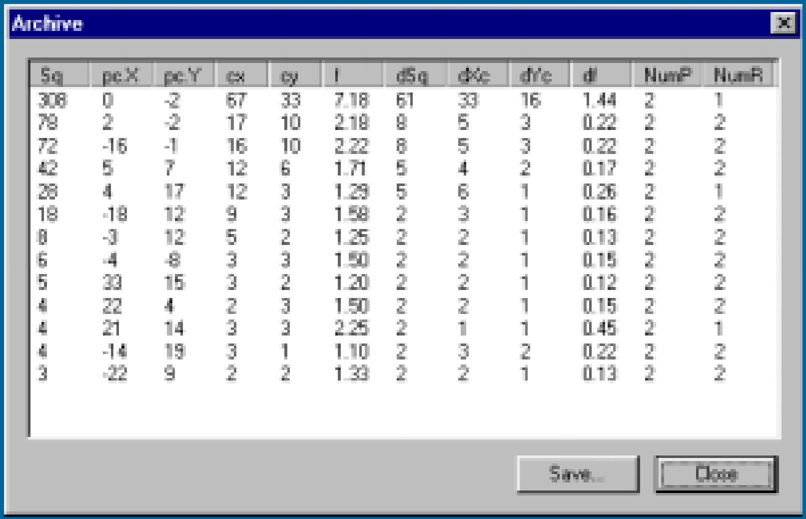
Extraction of cross fragments and rhombus fragments (a) from the input image of industrial objects; (b) - two types of combined textures are presented



Extraction of cross fragments fragments from the initial image
(crosses and the input image are combined)

2D Image Recognition





Archive

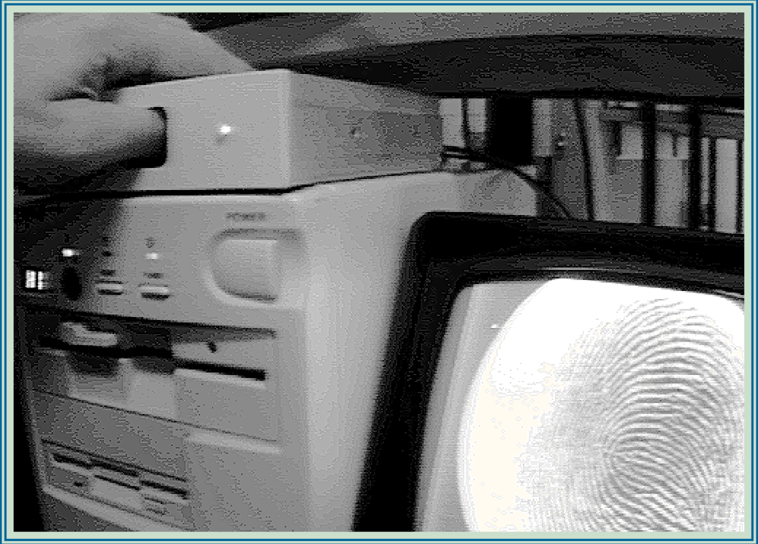
Sq	pcX	pcY	cx	cy	I	dSq	dXc	dYc	dI	NumP	NumR
308	0	-2	67	33	7.18	61	33	16	1.44	2	1
78	2	-2	17	10	2.18	8	5	3	0.22	2	2
72	-16	-1	16	10	2.22	8	5	3	0.22	2	2
42	5	7	12	6	1.71	5	4	2	0.17	2	2
28	4	17	12	3	1.29	5	6	1	0.26	2	1
18	-18	12	9	3	1.58	2	3	1	0.16	2	2
8	-3	12	5	2	1.25	2	2	1	0.13	2	2
6	-4	-8	3	3	1.50	2	2	1	0.15	2	2
5	33	15	3	2	1.20	2	2	1	0.12	2	2
4	22	4	2	3	1.50	2	2	1	0.15	2	2
4	21	14	3	3	2.25	2	1	1	0.45	2	1
4	-14	19	3	1	1.10	2	3	2	0.22	2	2
3	-22	9	2	2	1.33	2	2	1	0.13	2	2

Save...
Close

Extraction of a set of features, archiving and teaching

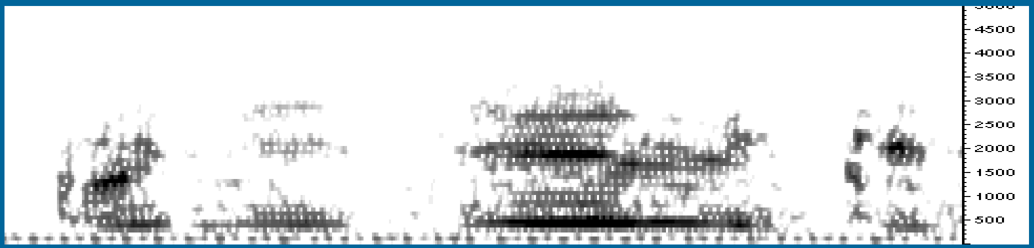
Biometric Applications

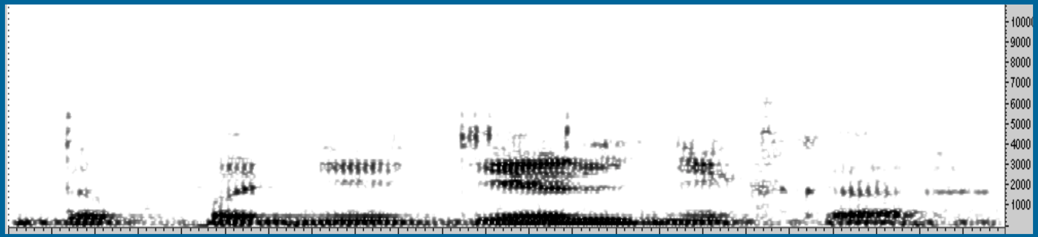
System for automated identification of a person by his palm



System for automated identification of a person by a fingerprint fragment

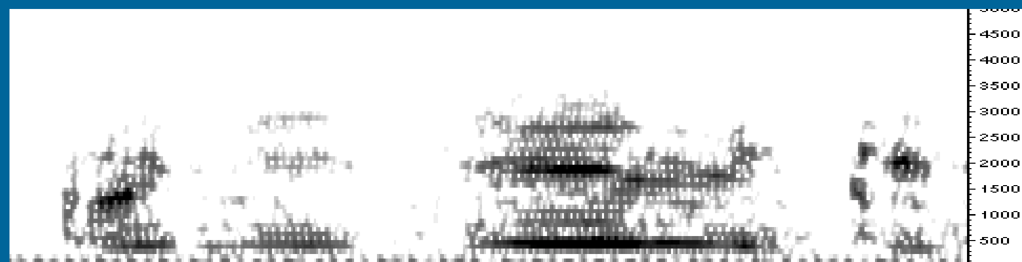
Music and Speech Recognition: Dynamic Spectrum of Human Voice Exhibits 2D Image to Be Processed





Dynamic spectra of human voice are specific for each person
Example of the same sentence said by two different people
("do ponedel'nika" - "by Monday")

Music and Speech Recognition: Dynamic Spectrum of Human Voice Exhibits 2D Image to Be Processed



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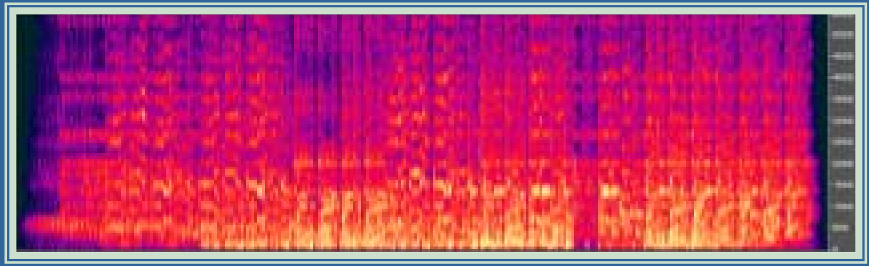
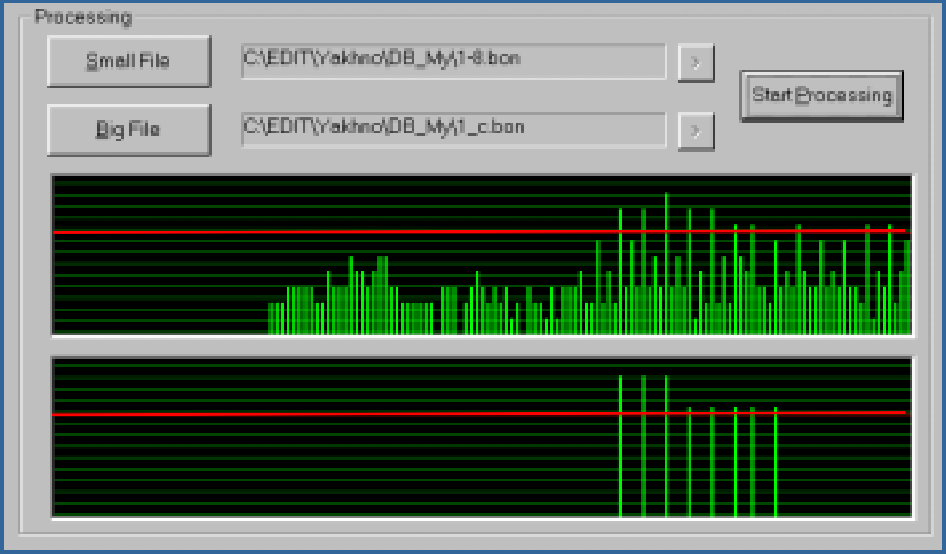
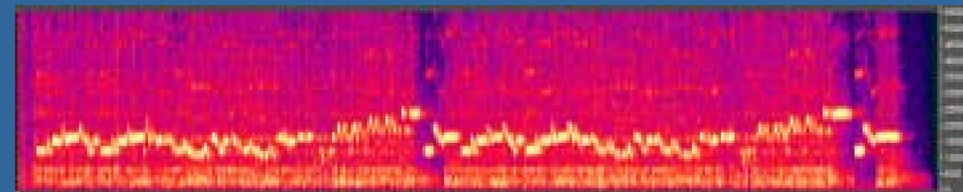
Music Recognition

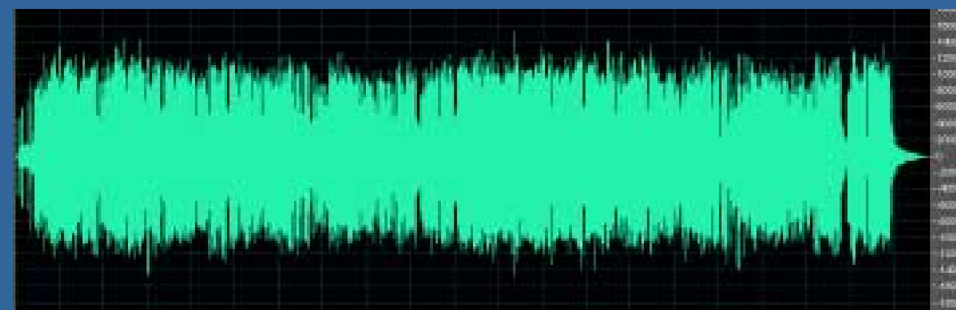


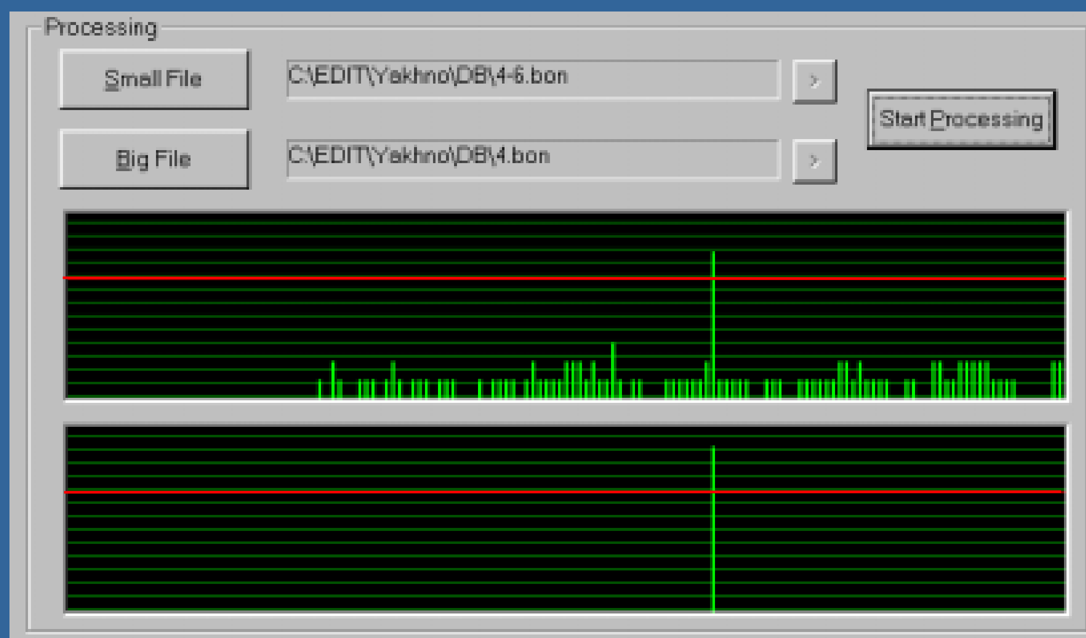


$\delta = 0.65$

Music Recognition







δ=0.65