Particles and Cosmology

16th Baksan School on Astroparticle Physics

SEARCH FOR ASTRO-GRAVITATIONAL CORRELATIONS: OGRAN AND BUST

D.Krichevskiy[1,2] , A. Gusev[1], S.Popov[1], V.Rudenko[1]

[1]Sternberg Astronomical Institute MSU

[2]Bauman Moscow Sate Technical University

Multimessenger astronomy

studies jointly various types of radiation emitted by a single cosmic source.

2017: observation of **electromagnetic and gravitational** radiation from the collision of two neutron stars GW170817

There is still **no** observation of **gravitational and neutrino** radiation from a single event!

Strategy of search for astro-gravitational correlations

Idea: look for GW-signals in the neighborhood of neutrinos' detection markers. This approach effectively reduces the amount of gravitational data to be analyzed, allowing for an improvement in the low signal-to-noise ratio with proper data processing.

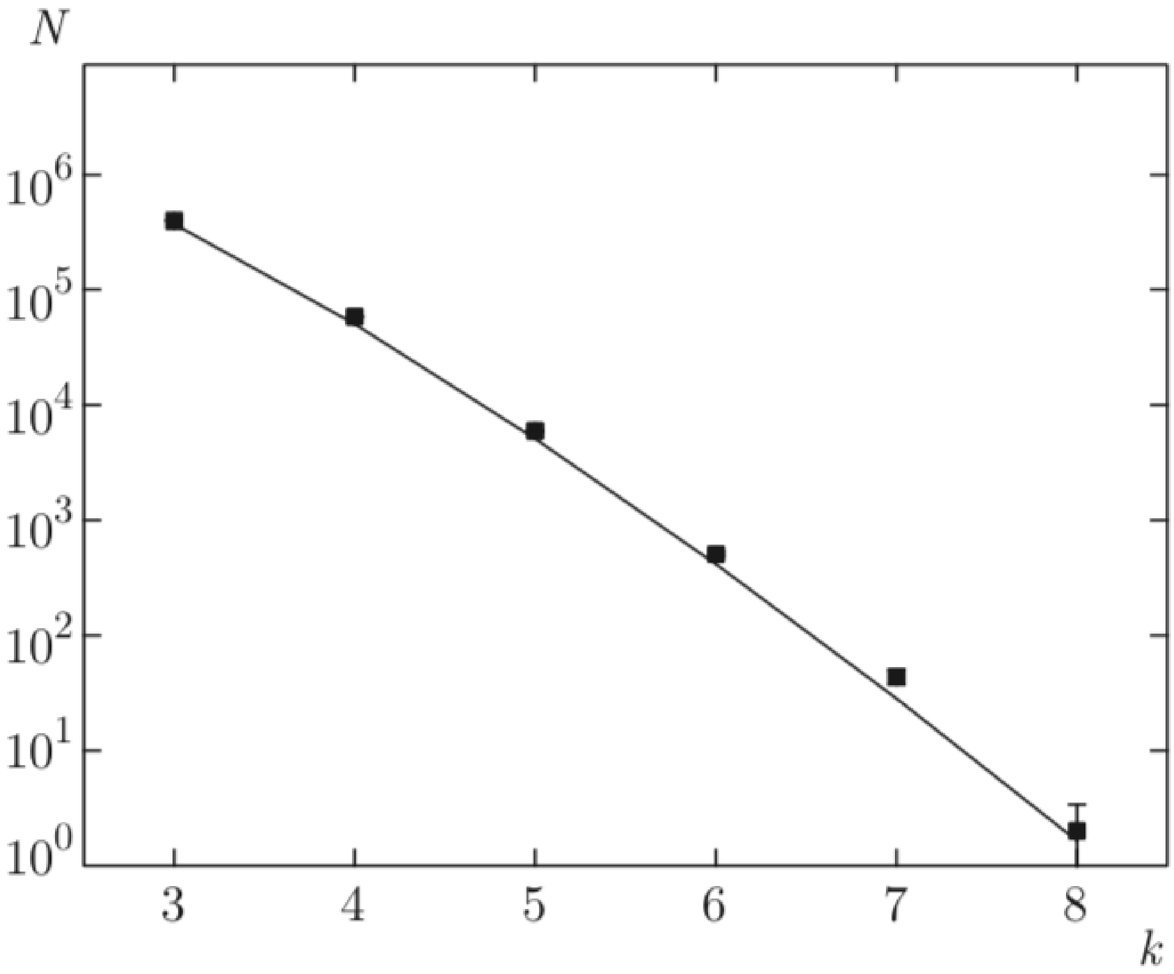
It's sensible to use BUST and OGRAN together!

Baksan Underground Scintillation Telescope (BUST)

- Effective depth – 850 m w.e.
- 8 scintillation surfaces, 3184 detectors, total scintillator’s mass (C_nH_{2n+2}, n ≈ 9) 340 t
- Main detection reaction

$$\bar{\nu}_e + p \rightarrow n + e^+$$

- Threshold detection energy E ≈ 9 MeV



The number of clusters containing k single events in the interval τ = 20 s

Events with k ≥ 9 caused probably not by noise.

During the observation period since 1980, not a single cluster was recorded with k ≥ 9.

Ю.Ф.Новосельцев, М.М. Болиев, В.И. Волченко и другие. Поиск нейтринных вспышек в галактике; 36 лет экспозиции (2017)

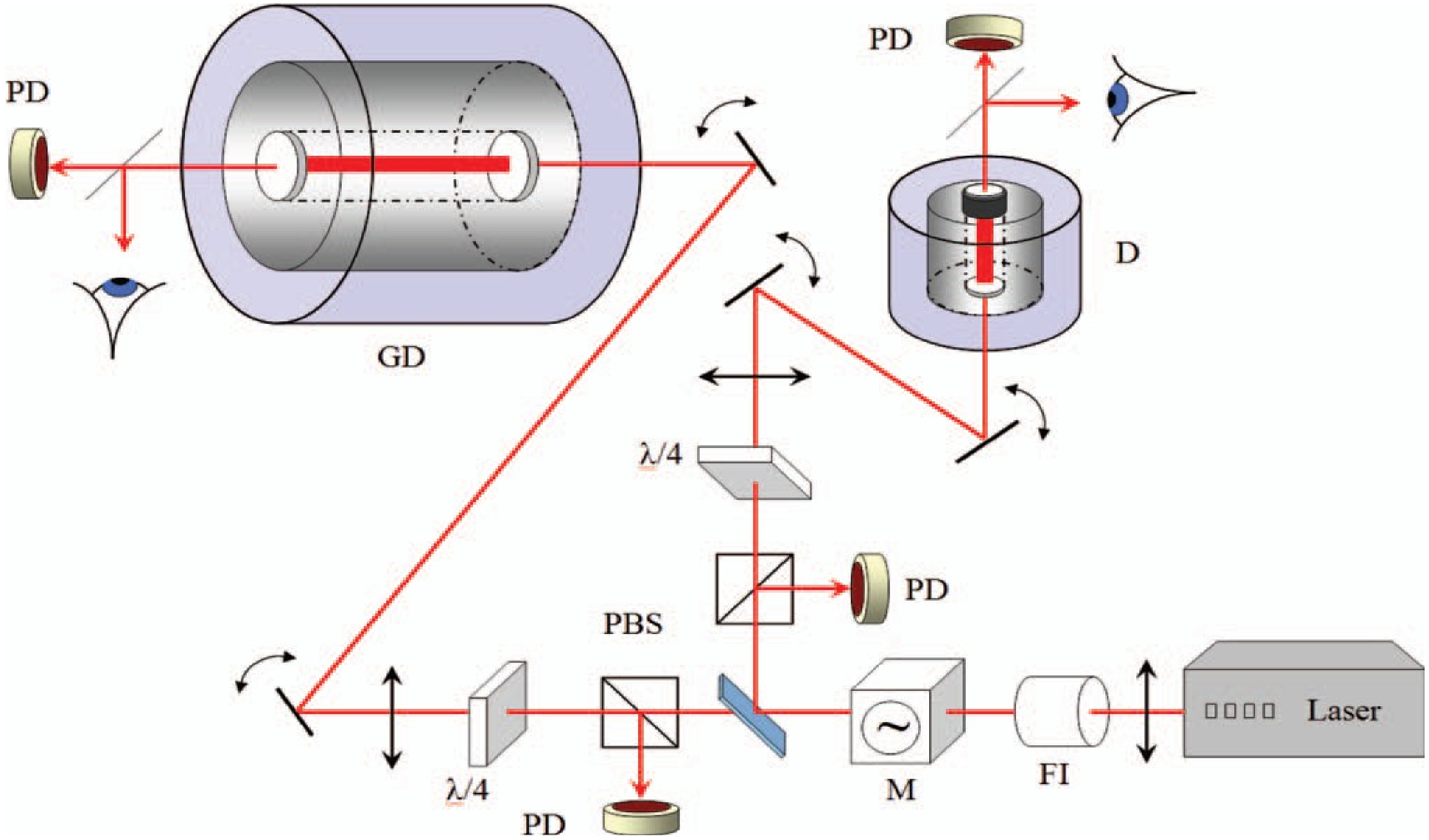
BUST surface

ИЯИ РАН Баксанская нейтринная обсерватория. Аналитическая справка (2015)

Opto-acoustic gravitational antenna (OGRAN)

Central element - acoustic resonator (M = 2.5 t, L = 2.3 m) with a central-axial channel forming the cavity of the Fabry-Perot optical standard, the mirrors of which are mounted on the ends of the cylinder with external laser pumping.

The principal opto-electronic scheme of the setup OGRAN.



GD - gravitational detector, PD - photo detector, D - discriminator, FI - Faraday isolator, M - modulator, and PBS - polarized beam splitter.

The combination of solid-state and interferometric principles of detection of GW gives advantages :

- GW impact on two degrees of freedom, acoustic and optical, creates a complex structure of the response, simplifying its filtering
- A low-noise optical recording system allows to achieve without cooling a sensitivity typical of cryogenic antennas ~ 10^{-19} at a band of 10 Hz near the resonant frequency of 1.3 kHz.

Gravitational collapse of a supernova

a powerful source of neutrino, gravitational and electromagnetic radiation

- Collapse of the nucleus due to gravitational pressure exceeding the radiation pressure
- Total energy released $E \sim 3\times10^{53}$ erg
- Collapse stars with $8M_{\odot} \leq M$.
- Expected frequency - 3 events per 100 years in the galaxy and neighborhood

Neutrino radiation from supernova collapse

Total neutrinos' energy $\sim$ 0.99E, single neutrino's mean energy $\sim$ 10 МэВ.

The main processes of neutrino release during collapse

- Electron-capture by the protons of the iron core :

$$p + e^- \rightarrow n + \nu_e.$$

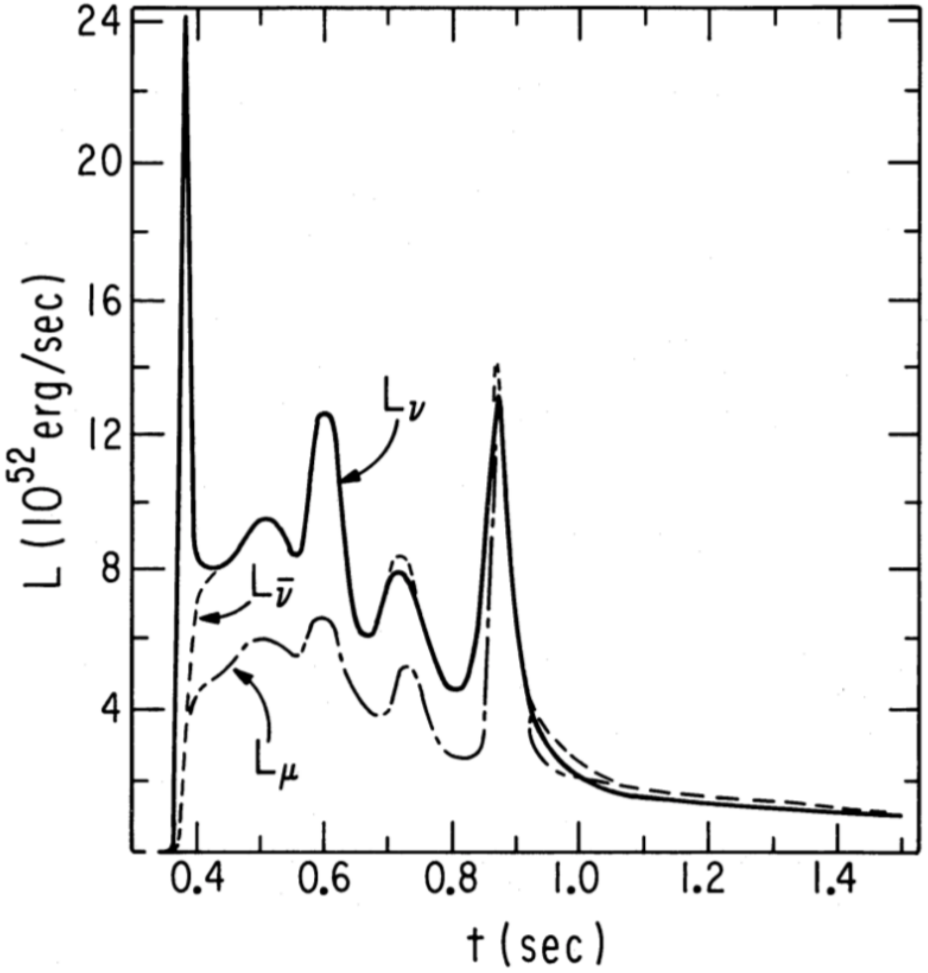
$\lesssim$5% of all neutrinos, $L \sim 10^{53}$ erg/s, $\tau \sim 0.01$ s

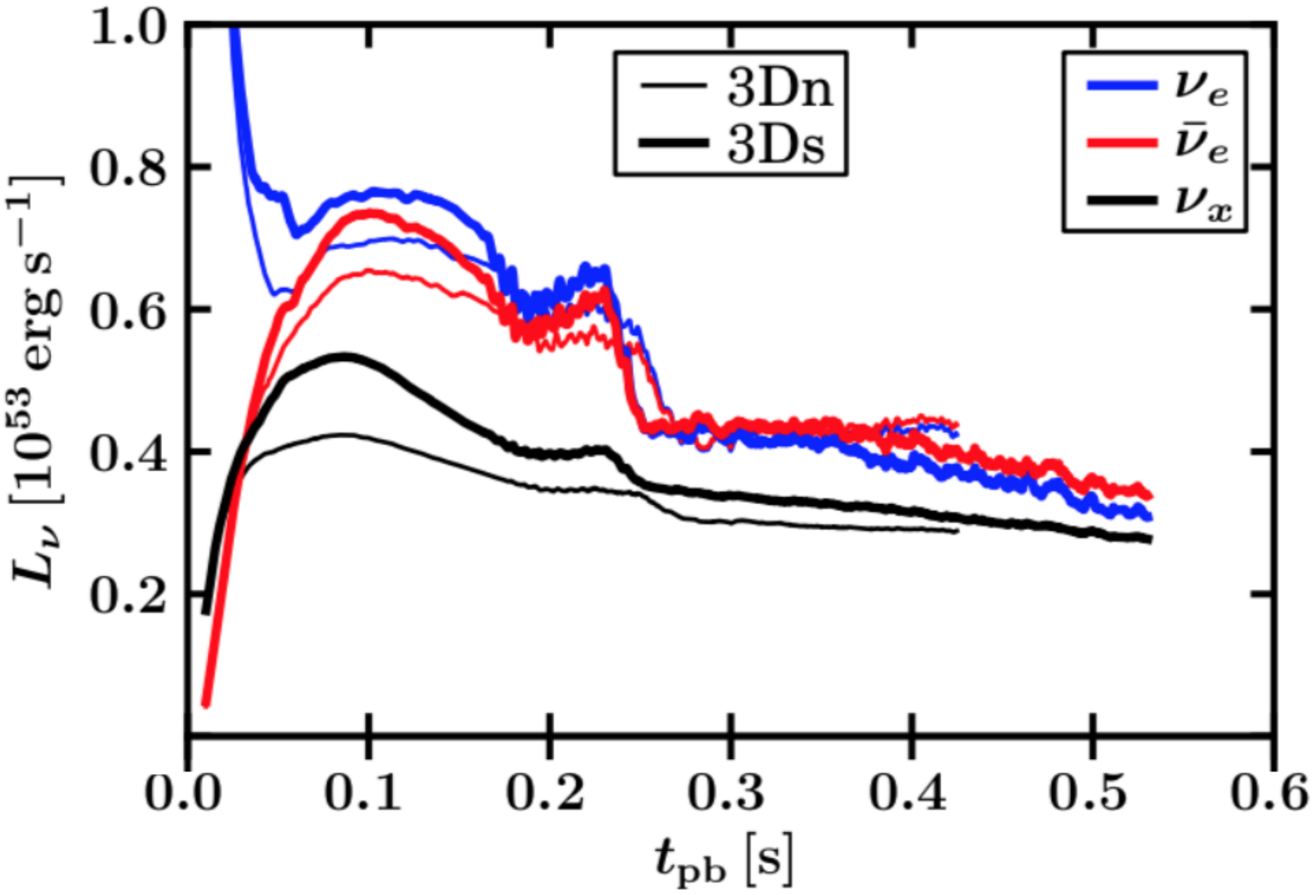
- Annihilation:

$$e^+ + e^- \rightarrow \tilde{\nu}_i + \nu_i,\ i = \mu,\tau,e,$$

$L \sim 10^{52}$ erg/s, $\tau \sim 10$ s

(M = 25M☉)





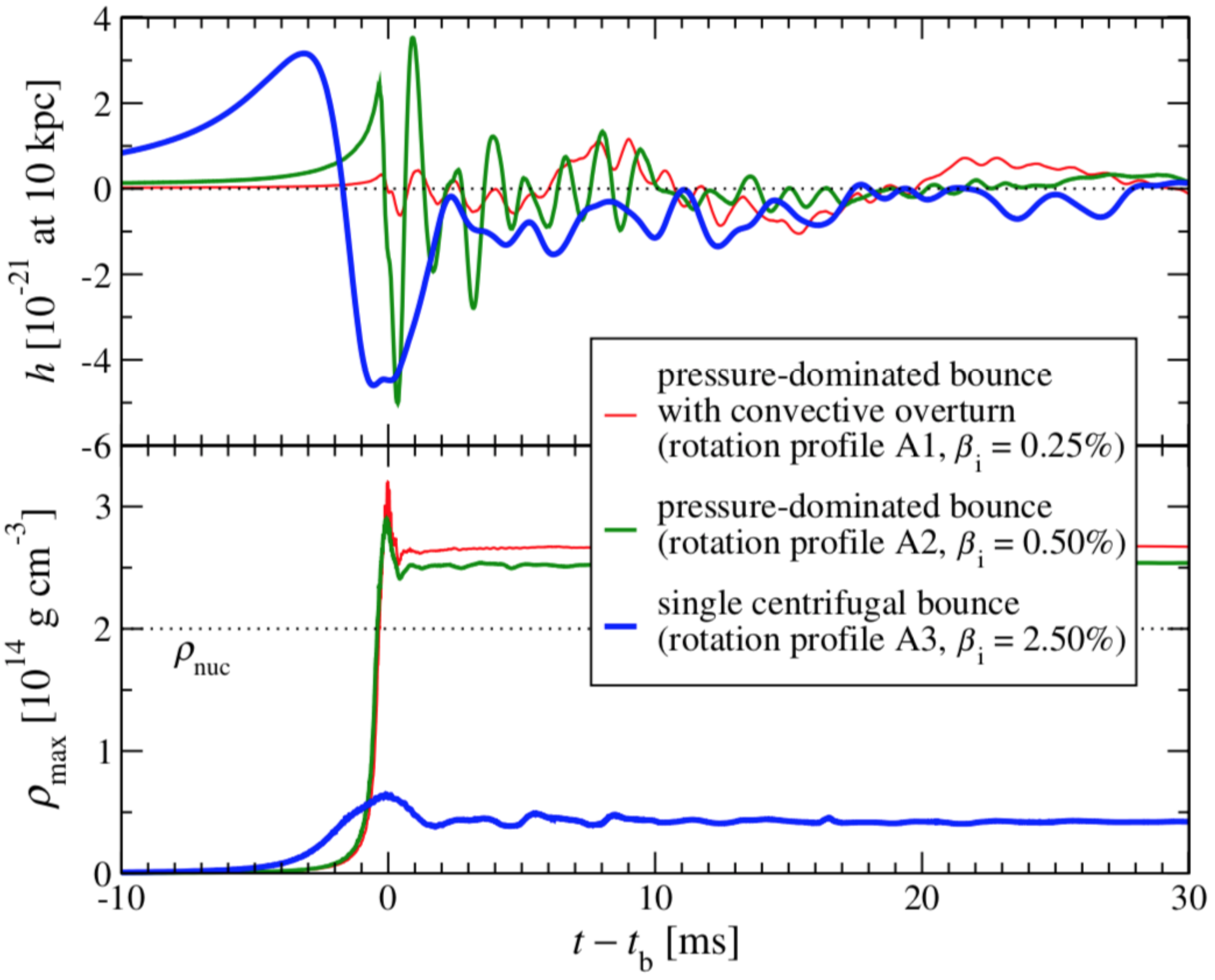
D.N. Schramm, R. Mayle, J.R. Wilson.
Neutrinos from gravitational collapse (1987)

*T.Melson, H.-T.Janka, R.*Bollig et al.
Neutrino-driven explosion of a 20 Solar-mass star in three dimensions enabled by strange-quark contributions to neutrino-nucleon scattering (2015)

Gravitational radiation from supernova collapse

GW occur due to the non-spherically symmetric motion of matter during collapse (third derivative of the quadrupole moment isn't 0).

- Expected magnitude $h \sim 10^{-22}$ - 10^{-20} (distance to source ∼ 10 kpc)
- Frequency of the wave packet $\nu \sim 1000$ Hz
- GW-burst energy ∼ $10^{44} – 10^{49}$ erg



$\beta_i = \left|\frac{T}{W}\right|$ – initial rotation parameter

H. Dimmelmeier, C.D. Ott, H.-T. Janka, A. Marek, and E. Müller.
The gravitational wave burst signal from core collapse of rotating stars (2007)

The processing algorithm carries information about both neutrino and gravitational statistics!

False alarm probability $P\{R_{max} > C_{\alpha} | \lambda = 0\} = \alpha$

$$1 - \alpha \cong \left[1 - exp\left(-\frac{C_{\alpha}^{2}}{2\sigma^{2}}\right)\right]^{\gamma}$$

- R_{max} – maximum value of the gravitational signal envelope $R(t)$ at intervals $\tau = 20$ s at the filter output
- C_{α} – threshold level (statistics is to known)
- γ is proportional to the number of intervals ($\tau = 20$ s) which are candidates for a neutrino event
- σ – noise dispersion

Current plans

1. development of a mathematical algorithm based on the theory of optimal filtering

2. increase the sensitivity of OGRAN
   - to the level of 10^{-20} by increasing the coefficient of opto-mechanical conversion of the antenna by forcing the parameters of its opto-electronic nodes
   - to the level of 3×10^{-21} by cooling of the detector body to the nitrogen temperature

Thank you for attention!