И.М. Железных, А.А. Миронович, С.Х. Караевский, В.И. Береснев (ЛНМДН и ЭЧ, ОФВЭ, ИЯИ РАН)

“РАЗРАБОТКА АЛЬТЕРНАТИВНЫХ МЕТОДОВ ДЕТЕКТИРОВАНИЯ КОСМИЧЕСКИХ НЕЙТРИНО СВЕРХВЫСОКИХ ЭНЕРГИЙ”

Семинар ОФВЭ,
Троицк, 4 марта, 2013

I. Введение.

- **Ранние годы физики нейтрино и нейтринной астрофизики высоких энергий (1957-1965)**
- **Проект DUMAND в США в 70-х – 80-х (F. Reines, J. Learned et al.)**
- **Программа «Советский ДЮМАНД» в СССР (80-е годы)**

II. Отдел Глубоководного Детектирования Нейтрино М.А. Маркова (ОГДН) как предшественник ЛНМДН и ЭЧ.

ОГДН (1981 - 1991 г.). Разработка альтернативных методов детектирования космических нейтрино.

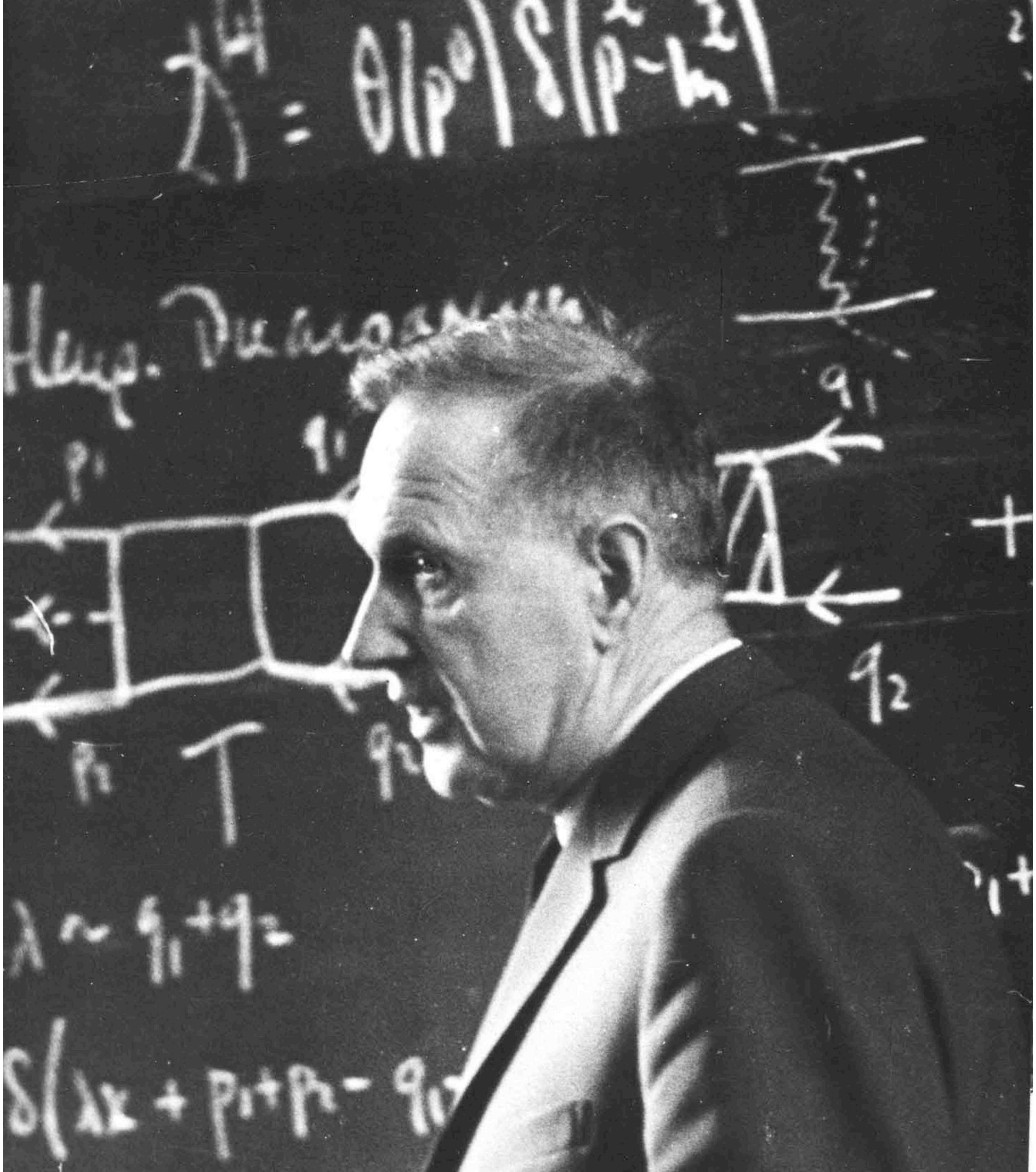
ОГДН (после 1991 г.). Разработка альтернативных методов детектирования космических нейтрино.

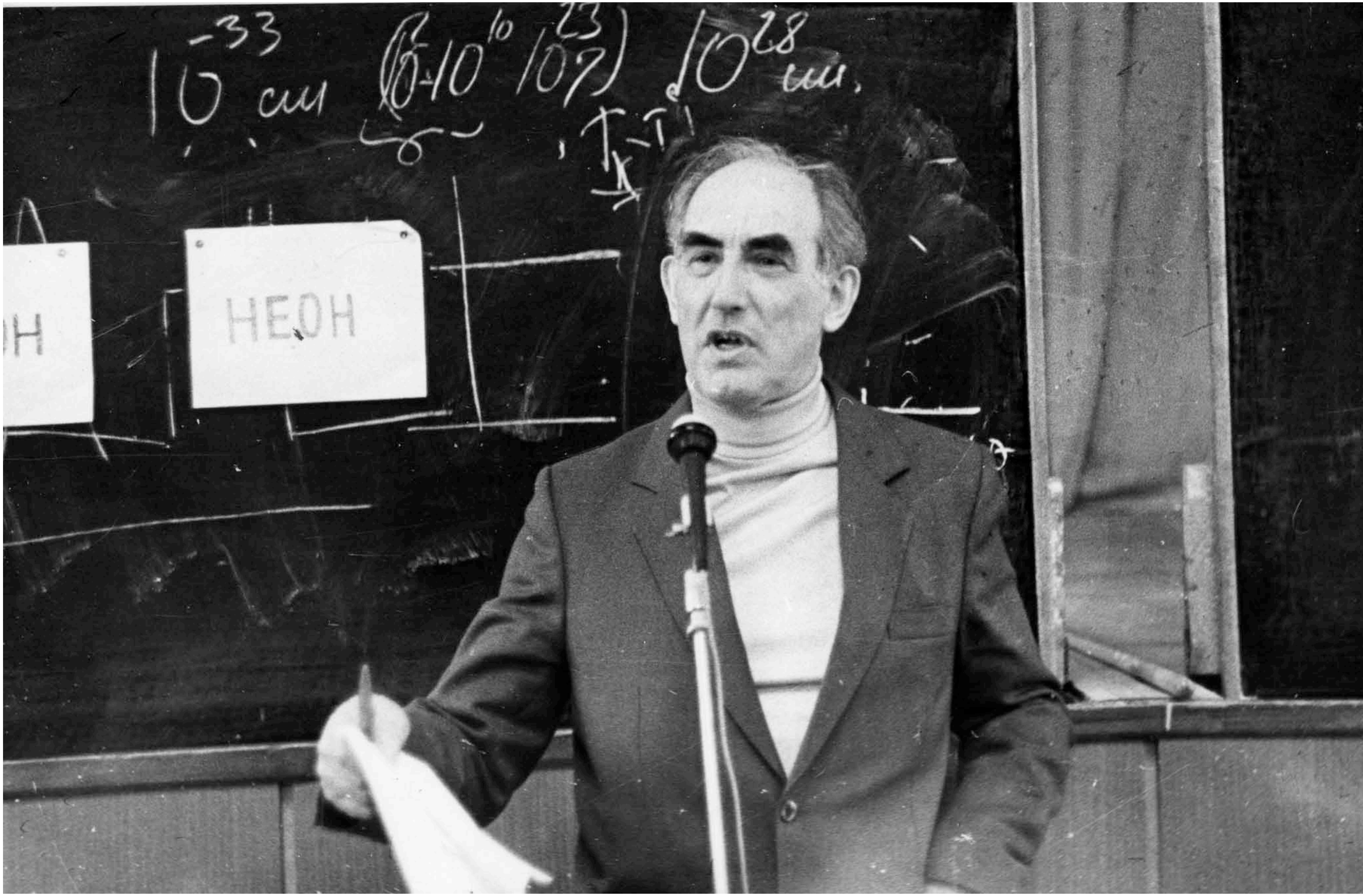
III. ЛНМДН и ЭЧ (с 2008 г.)

1. Введение.

- Предложение подземных нейтринных экспериментов (М.А. Марков, 1957).
- Первые дискуссии о нейтринной и гамма астрофизике (астрономии) высоких энергий в 1957 – 1961 г.г. с

М.А. Марковым, Я.Б. Зельдовичем, В.Л. Гинзбургом

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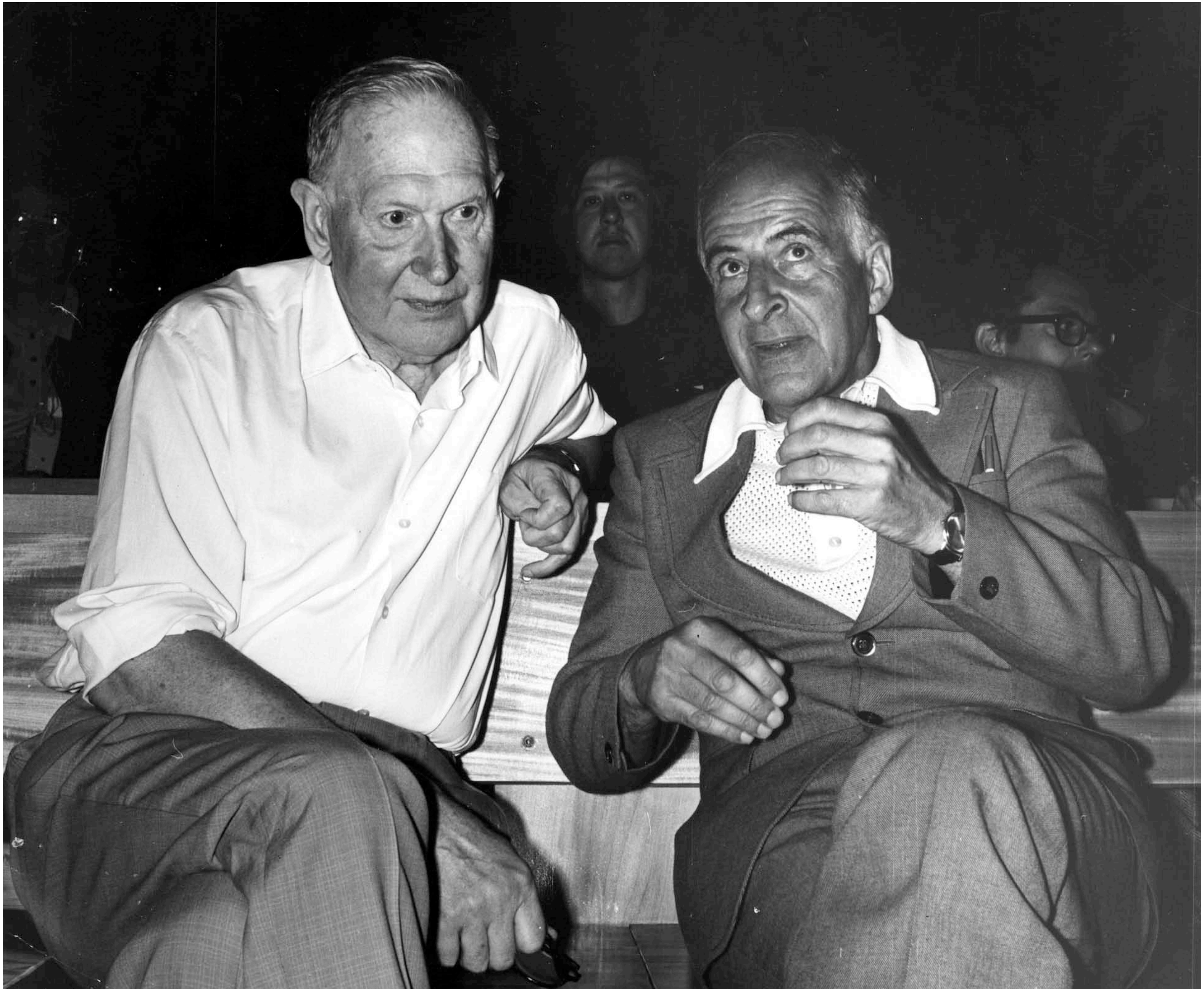


Вступление (продолжение)

2) Проект DUMAND в США (F. Reines, J. Learned et al., 1975):

- **Deep Underwater Muon And Neutrino Detector - крупномасштабный глубоководный (идея Моисея Александровича 1960 г.!) черенковский нейтринный телескоп (КМ3) для нейтринной астрофизики высоких энергий (>10^{10} эВ).**

In 70^{th} it was understood that kiloton HE neutrino telescopes which were under construction (Baksan et al) would not be able to register HE cosmic neutrinos.

1975: Fred Reines, John Learned, Arthur Roberts, Vic Stenger et al – idea of Gigaton underwater HE Neutrino Telescope (DUMAND).

1976 - 1979: Gurgen Askaryan et al, Ted Bowen, John Learned – idea of hydro-acoustic UHE neutrino detection.

So KM3 – cubic km - scale detector for HE and UHE Neutrino Astrophysics (Astronomy) – is needed !

3) Программа «Советский ДЮМАНД» в СССР (80-е годы) под руководством М.А. Маркова. Участники: 10 ведущих институтов АН СССР

«Советский ДЮМАНД» - это разработка

- методов глубоководного оптического и гидроакустического детектирования нейтрино,

- альтернативных нейтринных телескопов:

- **Radio Antarctic Muon And Neutrino Detection**
- **Radio Astronomical Method of Hadron And Neutrino Detection**

+ прикладные исследования

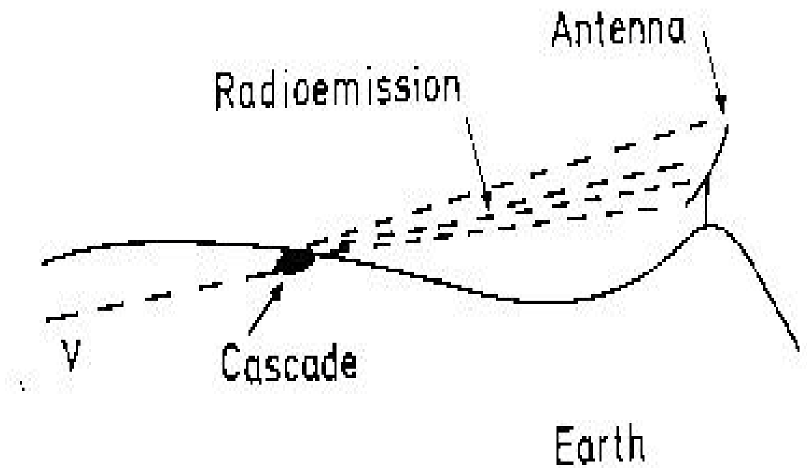
- **Avalanche Photo Diodes** – solid state PMTs
  New scintillators (liquid and plastic)

II. Отдел Глубоководного Детектирования Нейтрино под руководством М.А. Маркова (ОГДН образован в 1981 г.) как предшественник ЛНМДН и ЭЧ.

- **ОГДН (до 1991 г.). Результаты работ по программе ДЮМАНД в советский период : эксперименты в Средиземном море и на антарктической станции Восток (проект РАМАНД).**

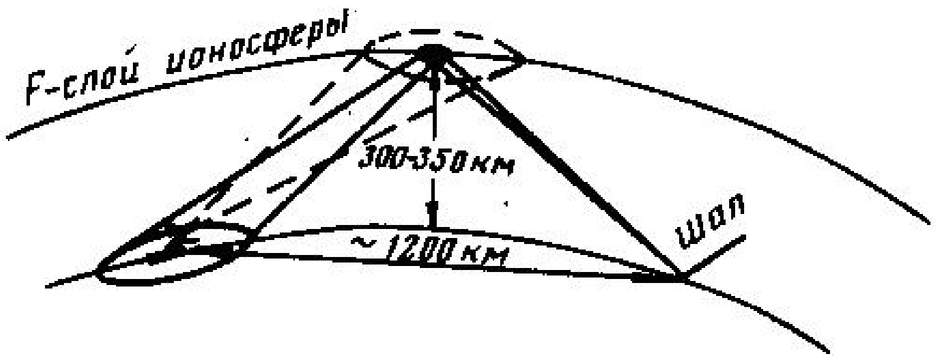
1981: ***L.Dedenko M. Markov, I. Zh*.,** *Proc. Neutrino-81, p. 292.*

It was proposed to detect electron-photon cascades, induced in the crust of the Earth by neutrinos from the lower hemisphere, whose development could continue in the atmosphere in direction close to horizontal. See also *V. Markov, I. Zh. (NIM, 1986)*



1982: ***L. Dedenko, G. Gusev, M. Markov and I. Zh.,*** *JETP Letters, 36, 216 (in Russian).*

About possibility of detecting radio emission of EAS and inclined showers from EHE neutrinos (E~10^20 eV) scattered after reflection from the ground and the Ionosphere

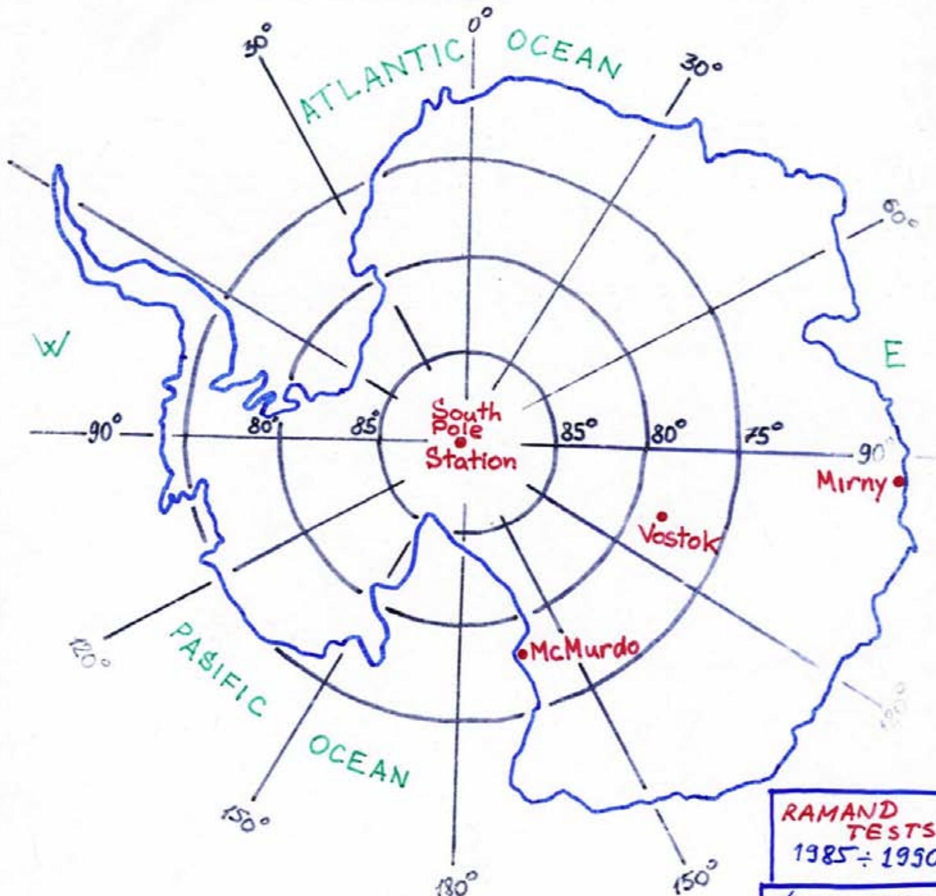


Radio Antarctic Muon And Neutrino Detection - **RAMAND**

The Antarctic ice as a neutrino target

(G. Gusev and I. Zheleznykh. 1983)

RAMAND in 1984-1990



ANTARCTICA

'Vostok' station - 78°28'S, 106°48'E

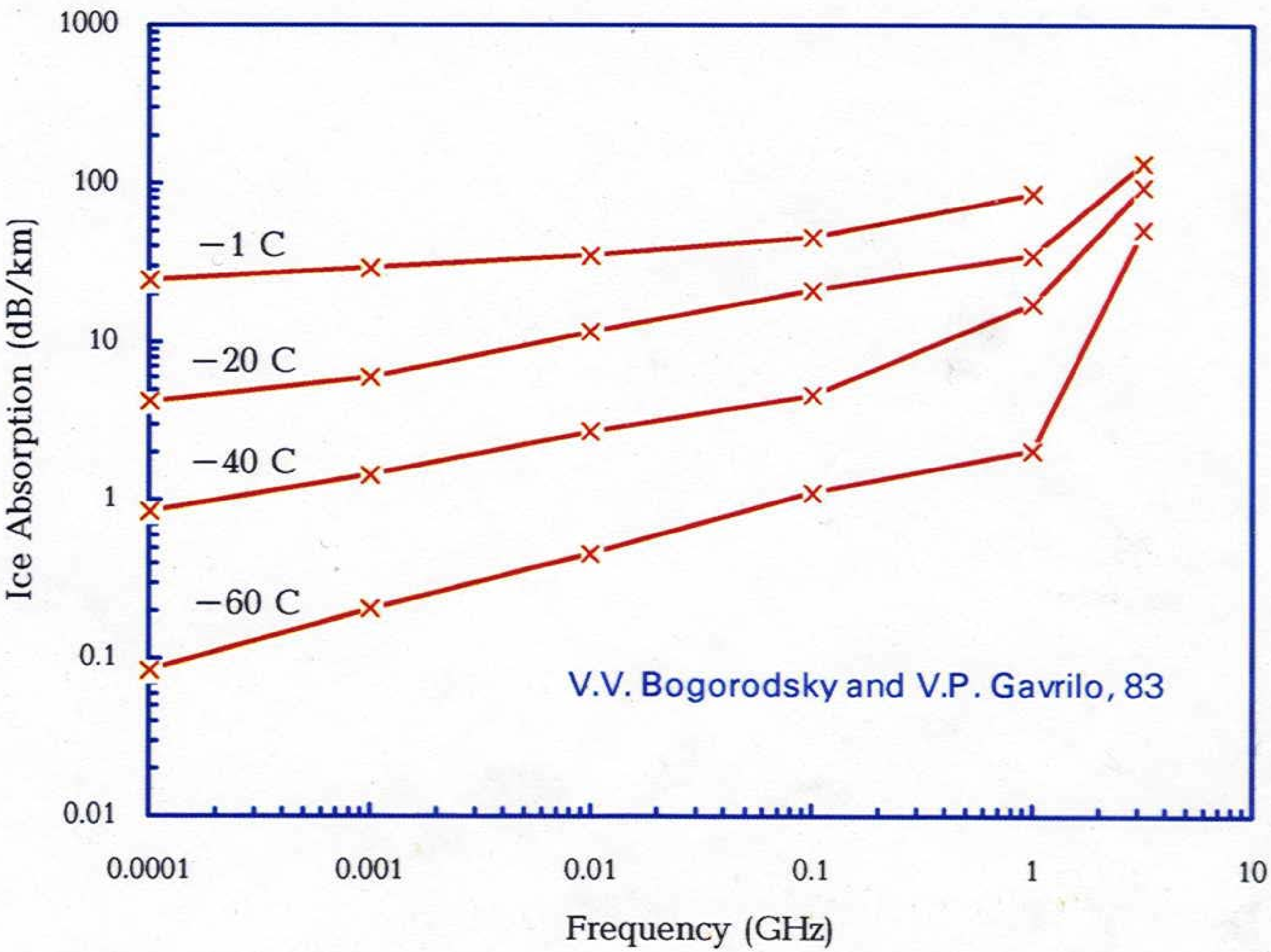
TWO RAMAND prototypes (3 and 7 antennae) were tested

RAMAND TESTS: 1985÷1990:

4 expeditions of INR in Antarctica (VOSTOK)

$T^{e.m.}_{By} < 500°$

Impulse ampl. characteristics



Ice absorption versus frequency
for the different temperatures

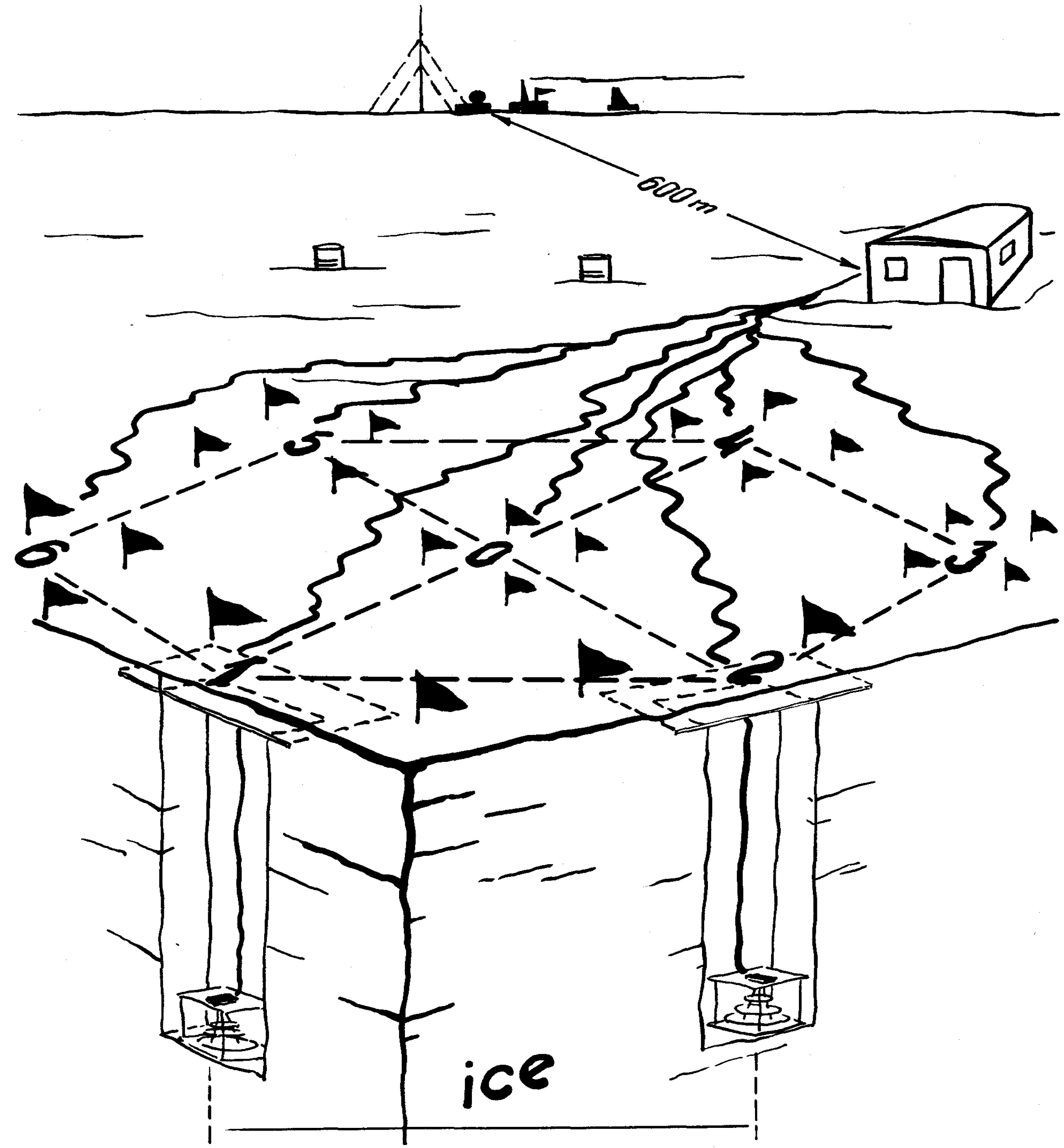
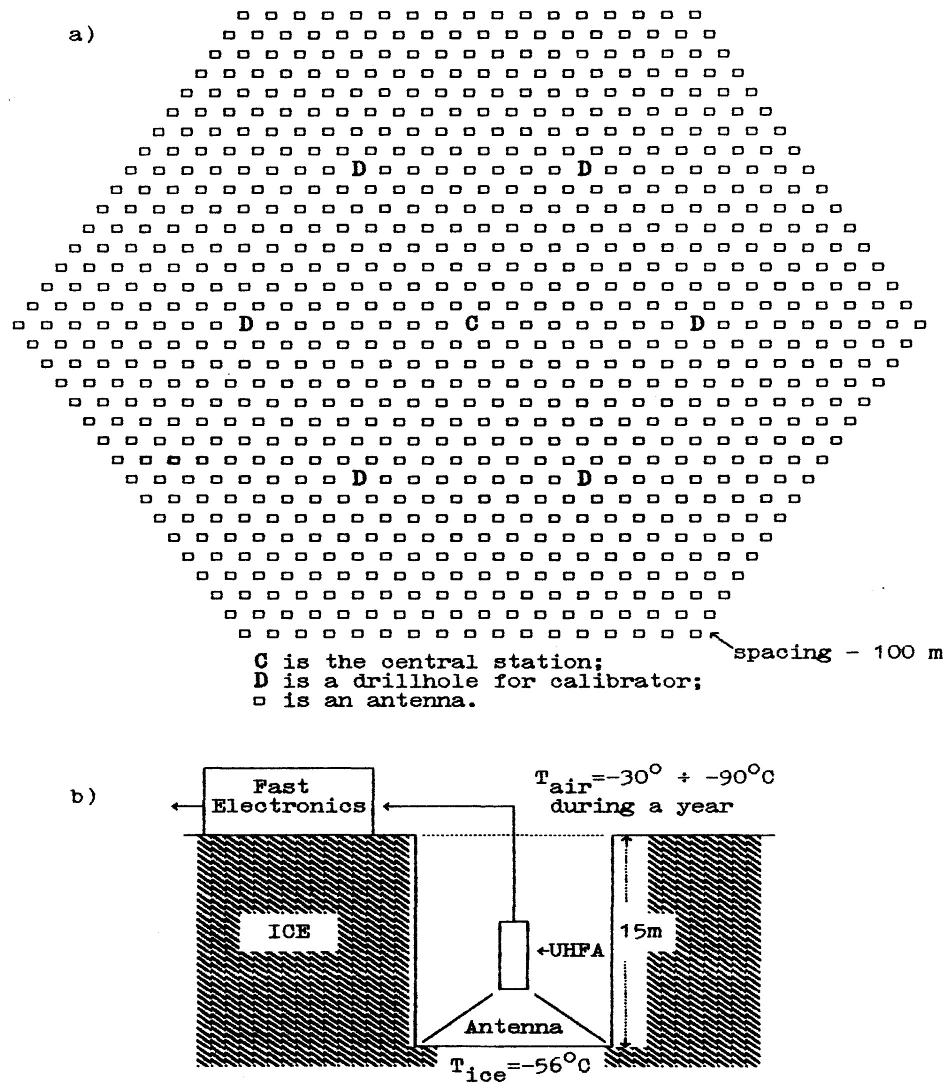


FIGURE 6

Рис.1 Работы на нейтринном полигоне станции "Восток". На переднем плане передвижная буровая установка. На заднем - балок (над снегом видна только крыша). Купол рядом - иглу, используемая как наружный склад.

Рис.2 Эксперимент по локации имитатора нейтринного сигнала. Передатчик опускается в скважину. На заднем плане - станция "Восток".



UHFM is a ultrahigh-frequency amplifier

FIGURE 9

Radio Astronomical Method of Hadron And Neutrino Detection - RAMHAND

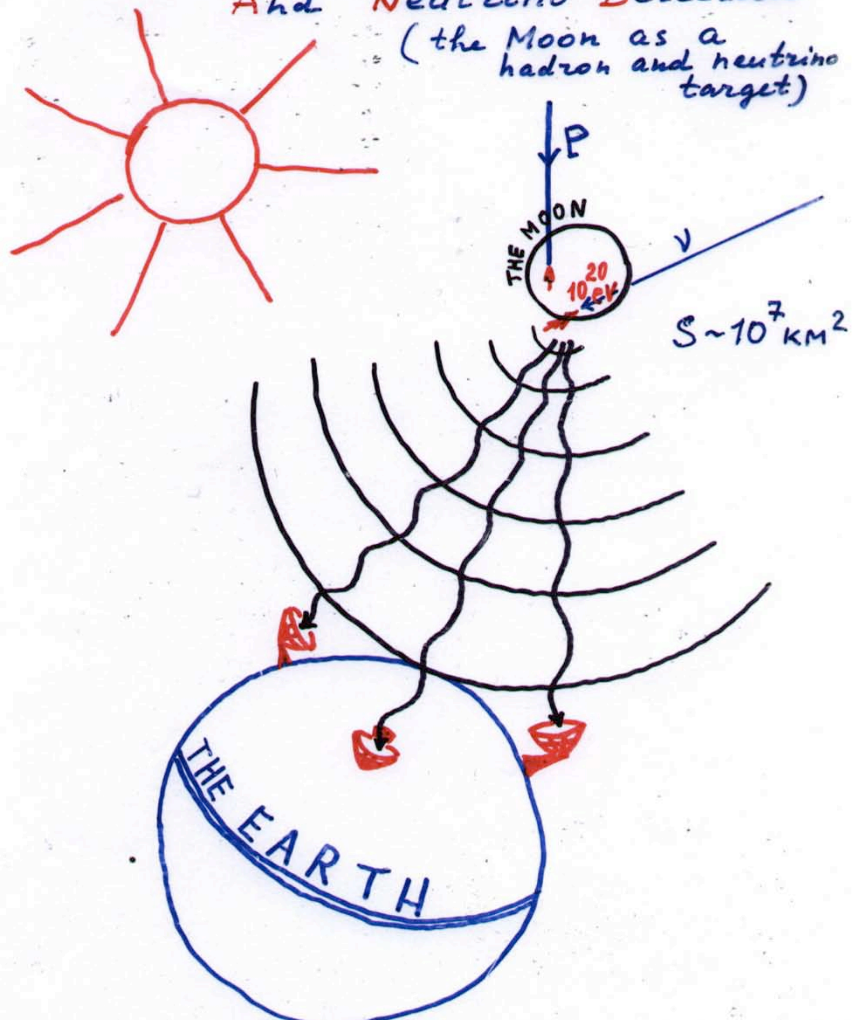
The Moon as a neutrino target

(R. Dagkesamanskii and I. Zheleznykh, 1989)

RAMHAND –

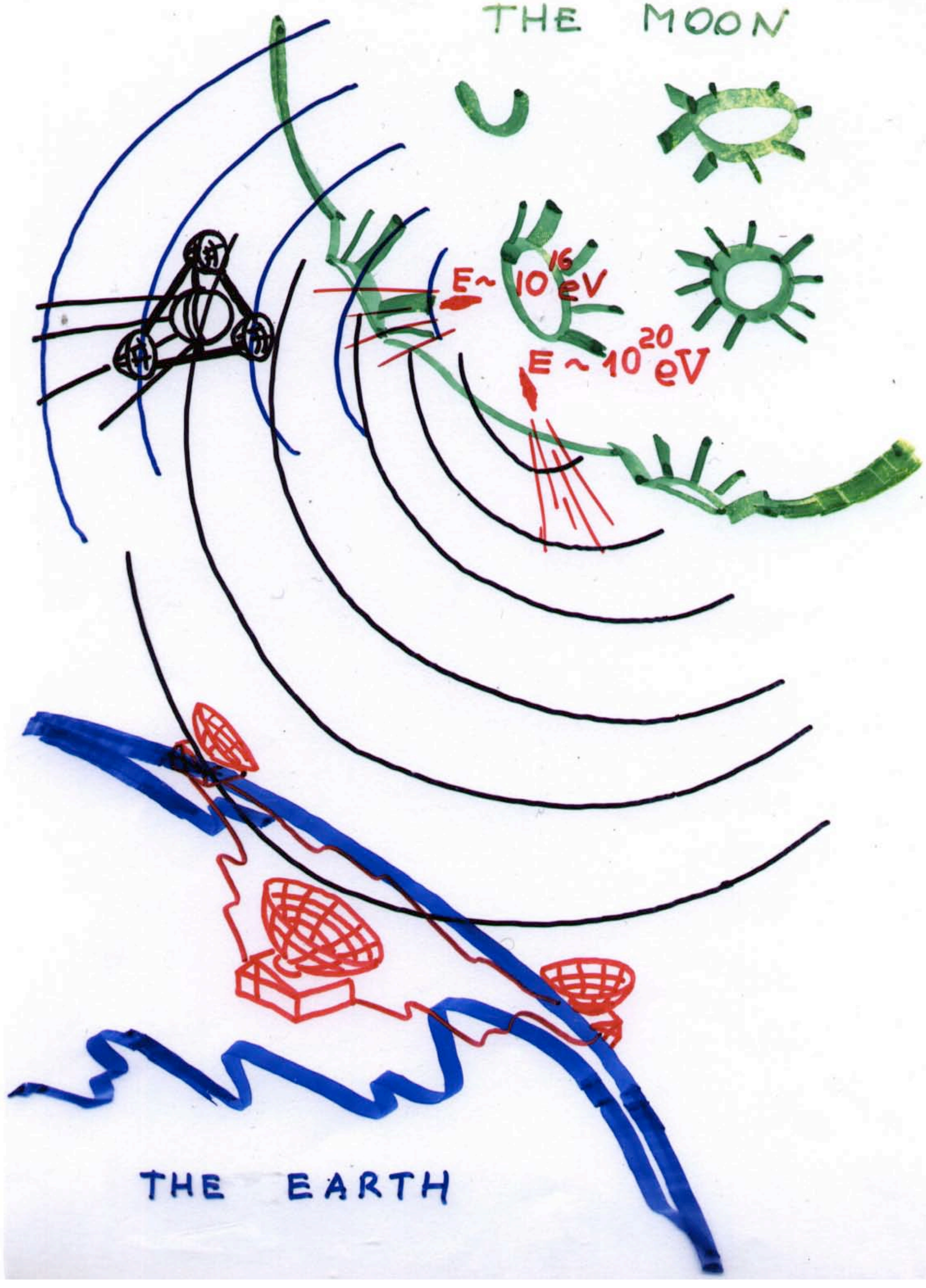
Radio Astronomical Method of Hadron And Neutrino Detection

(the Moon as a hadron and neutrino target)



RADIOEMISSION DENSITY $\sim \frac{W_{COHERENT}}{R^2} \sim \frac{E_\nu^2}{R^2}$

→ REGISTRATION DISTANCE $\sim E_\nu$


THE MOON
E~ 10^16 eV
E ~ 10^20 eV
THE EARTH

A cruise of the Soviet R/V "Dmitry Mendeleyev" in the Mediterranean sea

October, 1989

- The main goals of the cruise were deep-water investigations in the framework of the program «Soviet DUMAND», leaded at that time by M.A.Markov, and selection of a place for the future neutrino telescope (the Hellenic trench was considered as the favorite).
- For the purpose of organization the international cooperation on the high energy neutrino astrophysics in the Mediterranean «the international observers» (John Learned, Esso Flyckt, etc.) were invited by INR to participate at that cruise.
- One of the results of that cruise was the organization during the next two years (with Leonidas Resvanis active participation) of the Russian-Greek cooperation (NESTOR project, cruise of R/V “VITYAZ” in 1991)

1st Prototype of an autonomous Module of Deep Underwater Neutrino Telescope.

R/V "Dmitry Mendeleyev", October 1989

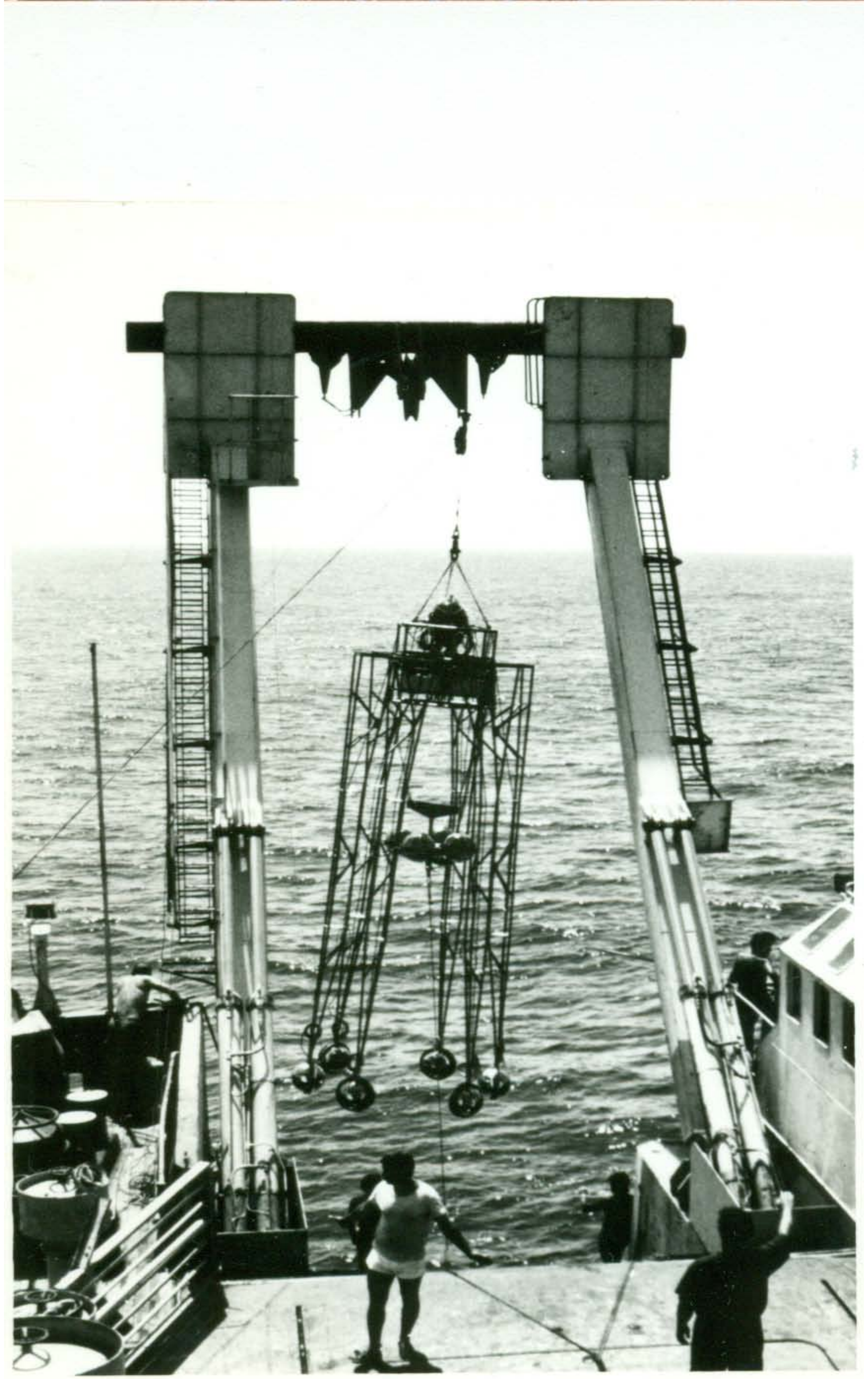
John Learned, Esso Flyckt et al. on the board of “Mendeleyev’

“VITYAZ” in Pylos, 1991

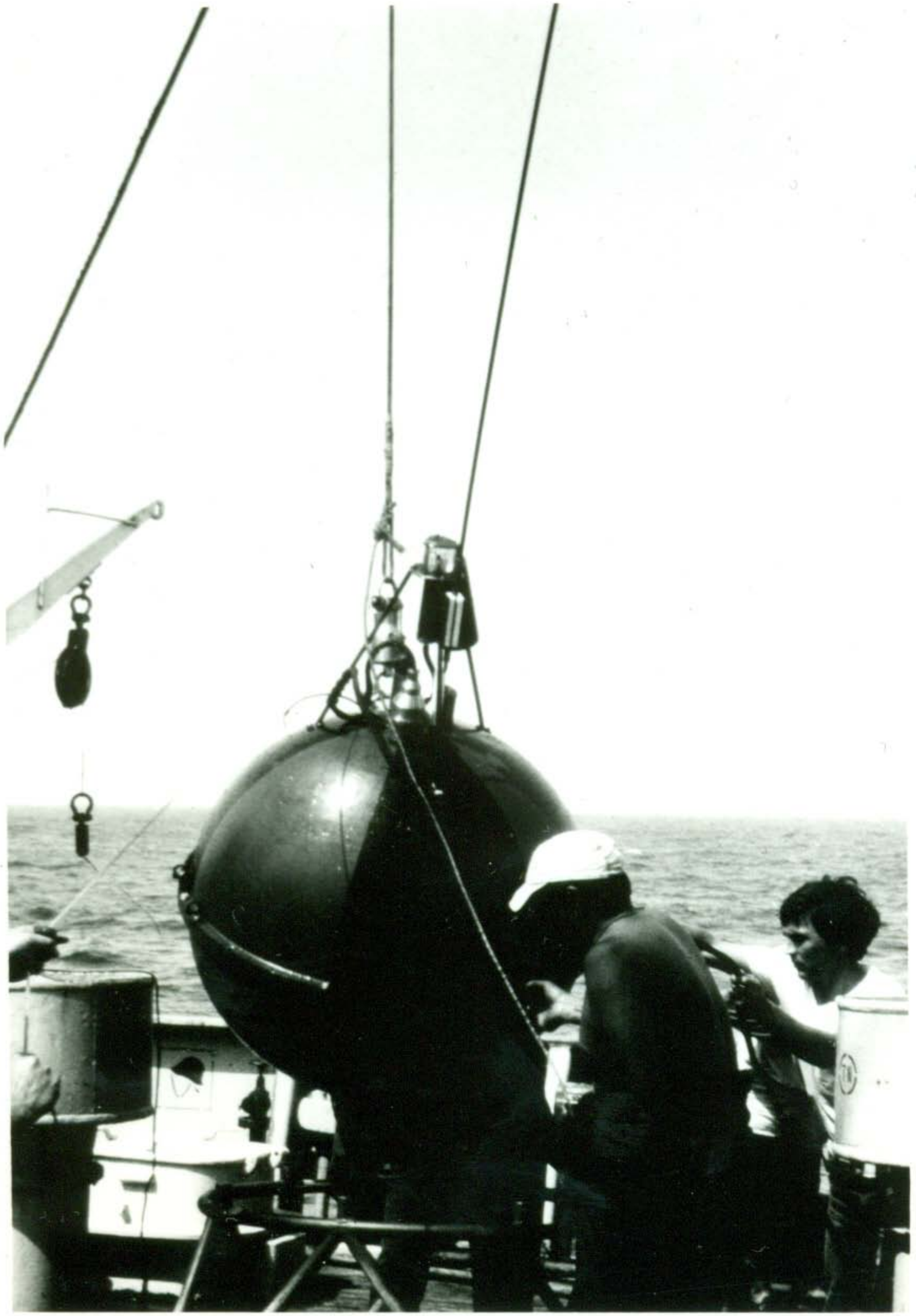
Leo Resvanis with captain and captain’s mates

“VITYAZ’ 1991 Preparation to deployment of muon detector – NESTOR’s flour prototype

VITYAZ’
1991.
Deployment
of NESTOR
flour
prototype of
10 PMTs



1991
Deployment
of SADCO
module for
measurement
of acoustic
BG at 4 km
depths



Some Results of the Soviet DUMAND project

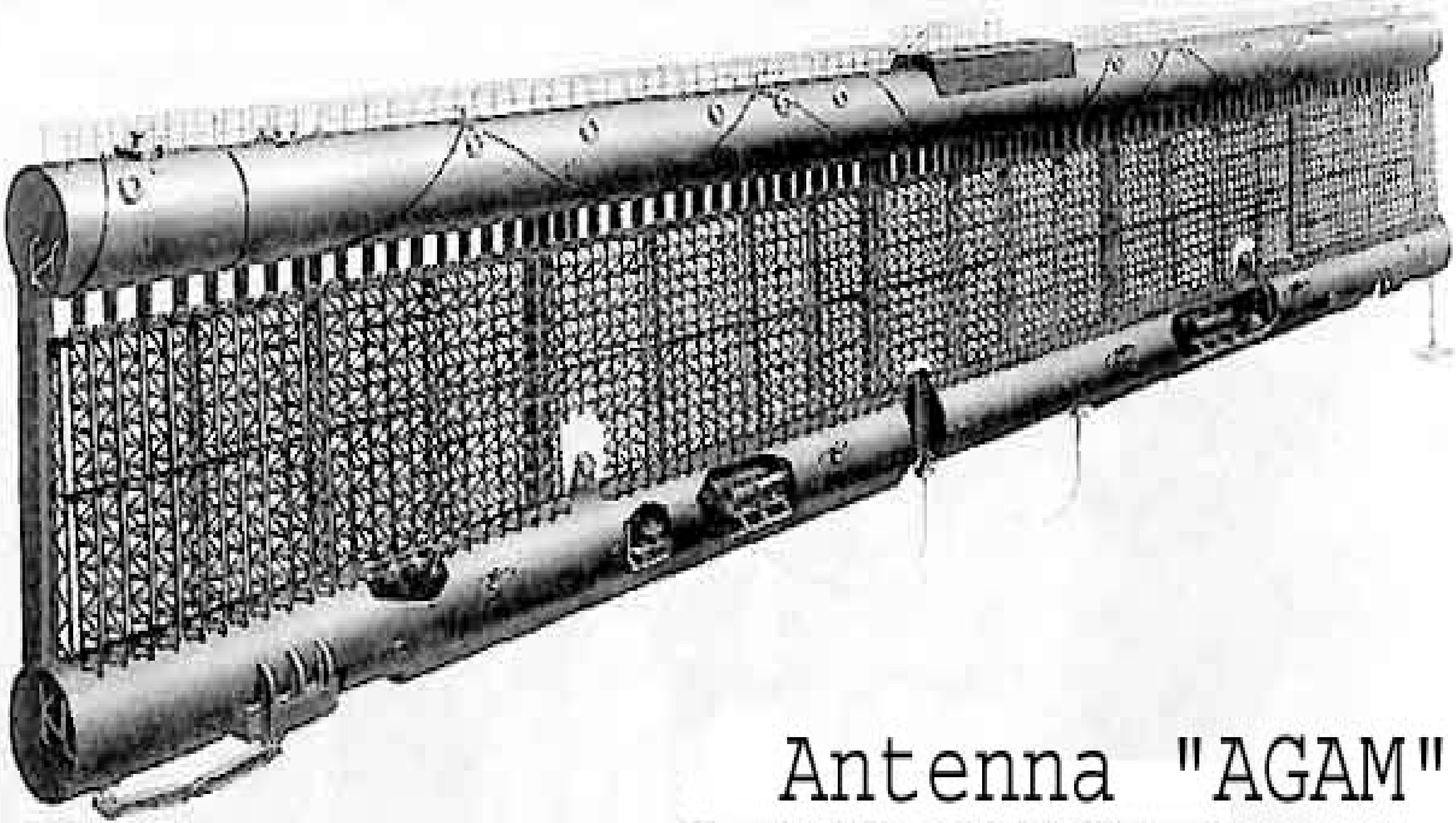
Soviet DUMAND = not only Deep Underwater
but Deep Underice
and Undermoon Researches also:

- Development of the Baikal NT
- Investigations in the Mediterranean Sea (4 expeditions): deep underwater muon and acoustical experiments, development of the NESTOR project
- Suggestions and development of Radio Methods for Detection of Neutrinos (using the **Askaryan idea of 1961 and 1965** to detect coherent Cherenkov radio emission of e.m. cascades produced by CRs in dielectric media)
- As result:

suggestion of using not only the World Ocean but the **Antarctic** ice and **the Moon** as **large- scale neutrino targets.**

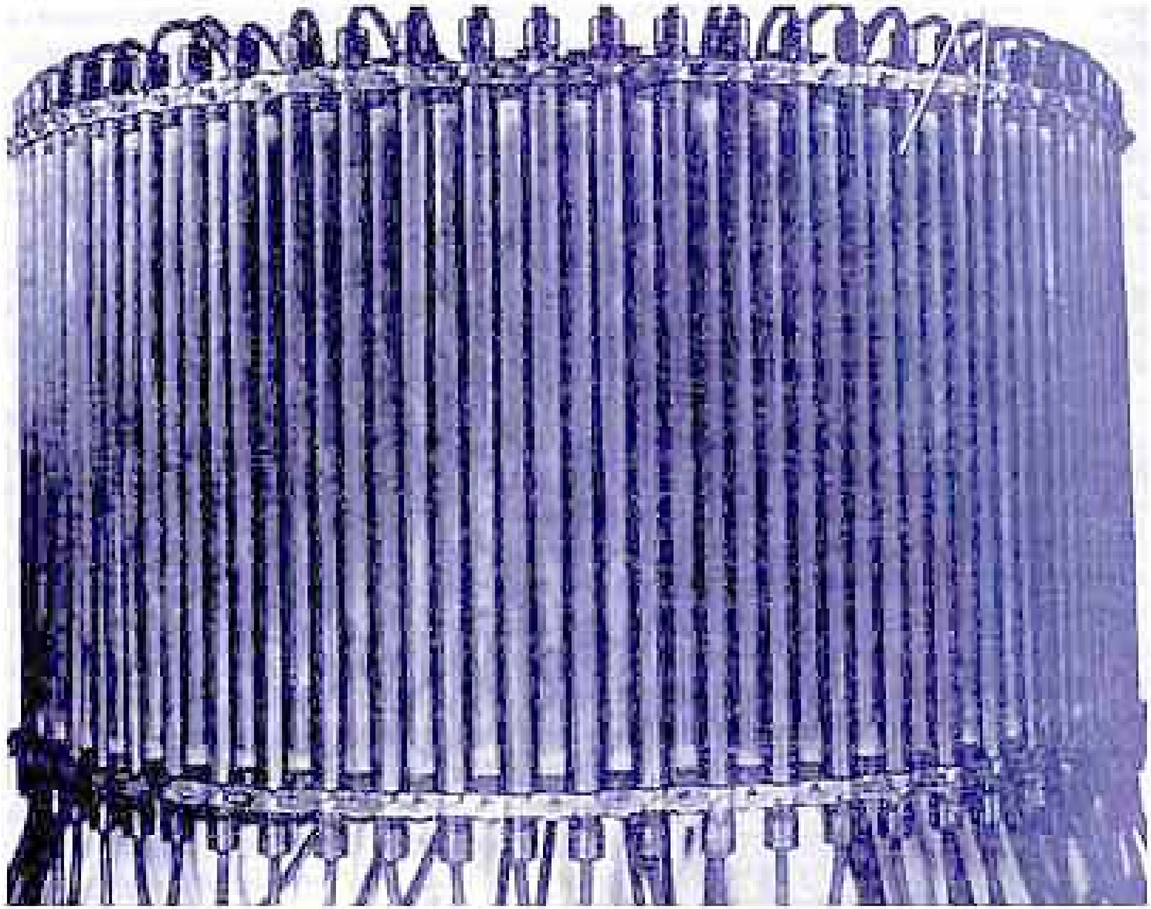
III. ОГДН (после 1991 г.). Разработка альтернативных методов детектирования космических нейтрино.

SADCO – **S**ea **A**coustic **D**etection of **C**osmic **O**bjects **(Development of hydro-acoustical neutrino detection using existing deep-water acoustical arrays in 90th)**



Antenna "AGAM"
(near Kamchatka)

IV. PORTABLE SUBMARINE ANTENNA MG-10M
as a basic module of the deep-water Neutrino Telescope



M = 1200 kg

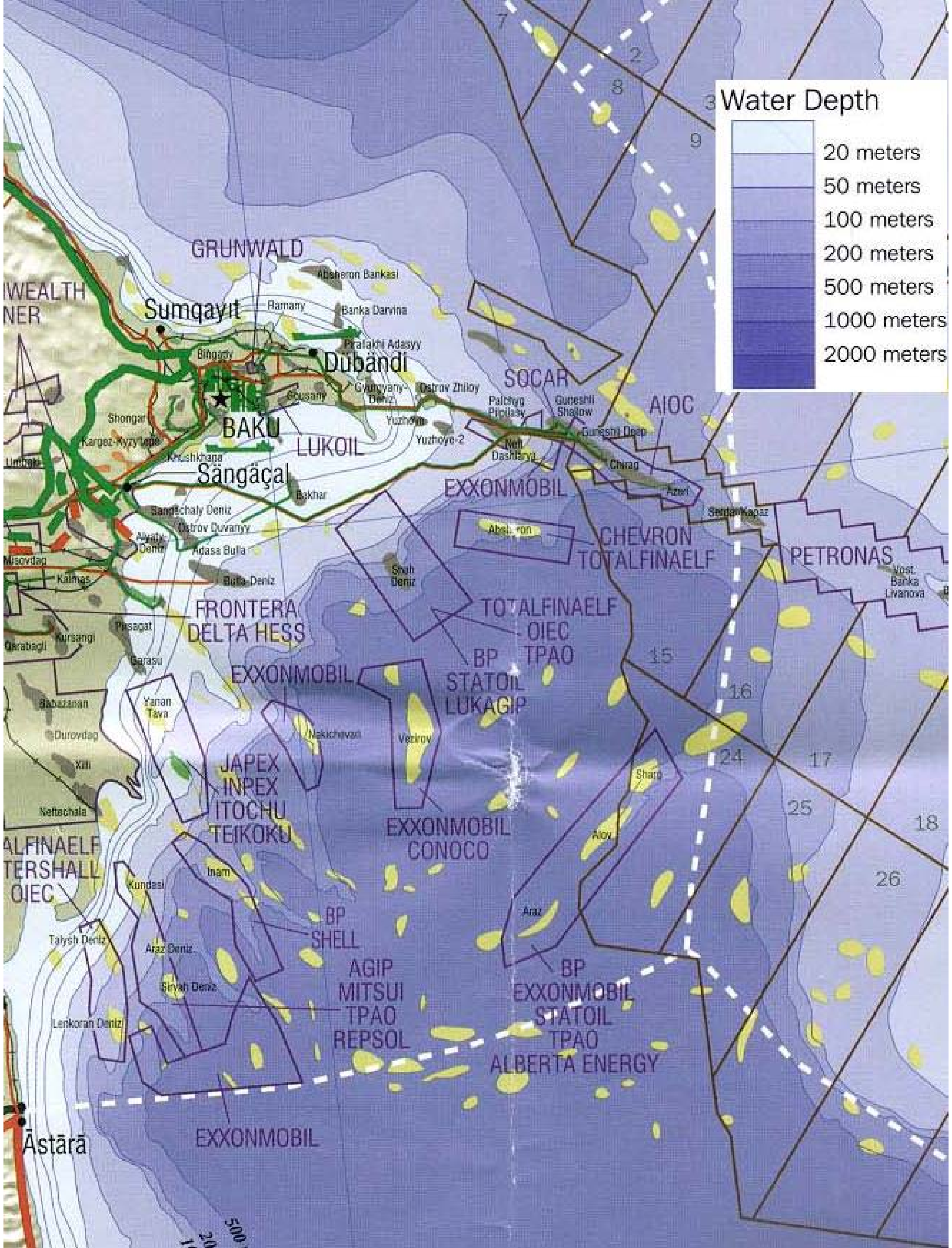
D = 1.6 m

H = 1.0 m

132 hydrophones

BW up to 25kHz

Sensitivity
~ 0.17 mV/Pa
(F = 3.5 kHz)


Water Depth
20 meters
50 meters
100 meters
200 meters
500 meters
1000 meters
2000 meters
GRUNWALD
Absheron Bankasi
Sumqayıt
Ramany
Banka Darvina
Pirallahi Adasyy
Dübändi
SOCAR
AIOC
BAKU
LUKOIL
Ostrov Zhiloy
Gunashli Shallow
Guneshli Deep
Neft Dashlary
Chirag
Azeri
Säŋgäçal
Bakhar
Shongar
Umbaki
EXXONMOBIL
Absheron
CHEVRON
TOTALFINAELF
PETRONAS
Serdar/Kapaz
Vost. Banka Livanova
Sangachaly Deniz
Ostrov Duvanyy
Alyaty Deniz
Adasa Bulla
Bulla Deniz
Shah Deniz
Misovdag
Kalmas
FRONTERA
DELTA HESS
TOTALFINAELF
OIEC
TPAO
BP
STATOIL
LUKAGIP
Pirsagat
Kursangi
Qarabagli
Garasu
EXXONMOBIL
Yanan Tava
Nakhchevan
Vezirov
Babazanan
Durovdag
Xilli
JAPEX
INPEX
ITOCHU
TEIKOKU
Neftechala
EXXONMOBIL
CONOCO
Sharg
Alov
Araz
ALFINAELF
TERSHALL
OIEC
Kurdasi
Inam
BP
SHELL
Talysh Deniz
Araz Deniz
Sirvan Deniz
AGIP
MITSUI
TPAO
REPSOL
BP
EXXONMOBIL
STATOIL
TPAO
ALBERTA ENERGY
Lenkoran Deniz
Āstārā
EXXONMOBIL
1
2
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26

Kalyazin 64-meter radio telescope, used in Russian RAMHAND experiment.

Main advantage of the radio telescope is a possibility to search with it the nanosecond pulses from the Moon simultaneously at several frequencies. During Kalyazin experiment we made simultaneous observations at 1.4 GHz and 2.3 GHz in both circular polarizations.

IV. ЛНМДН и ЭЧ (с 2008 г.)

1) Проект НЕСТОР-САДКО: Разработка программы сотрудничества ИЯИ РАН, российских и европейских институтов в создании в Средиземном море нейтринного телескопа, в проведении междисциплинарных (гидроакустических, океанологических, экологических) исследований.

2) Проекты РАМАНД и РАМХАНД

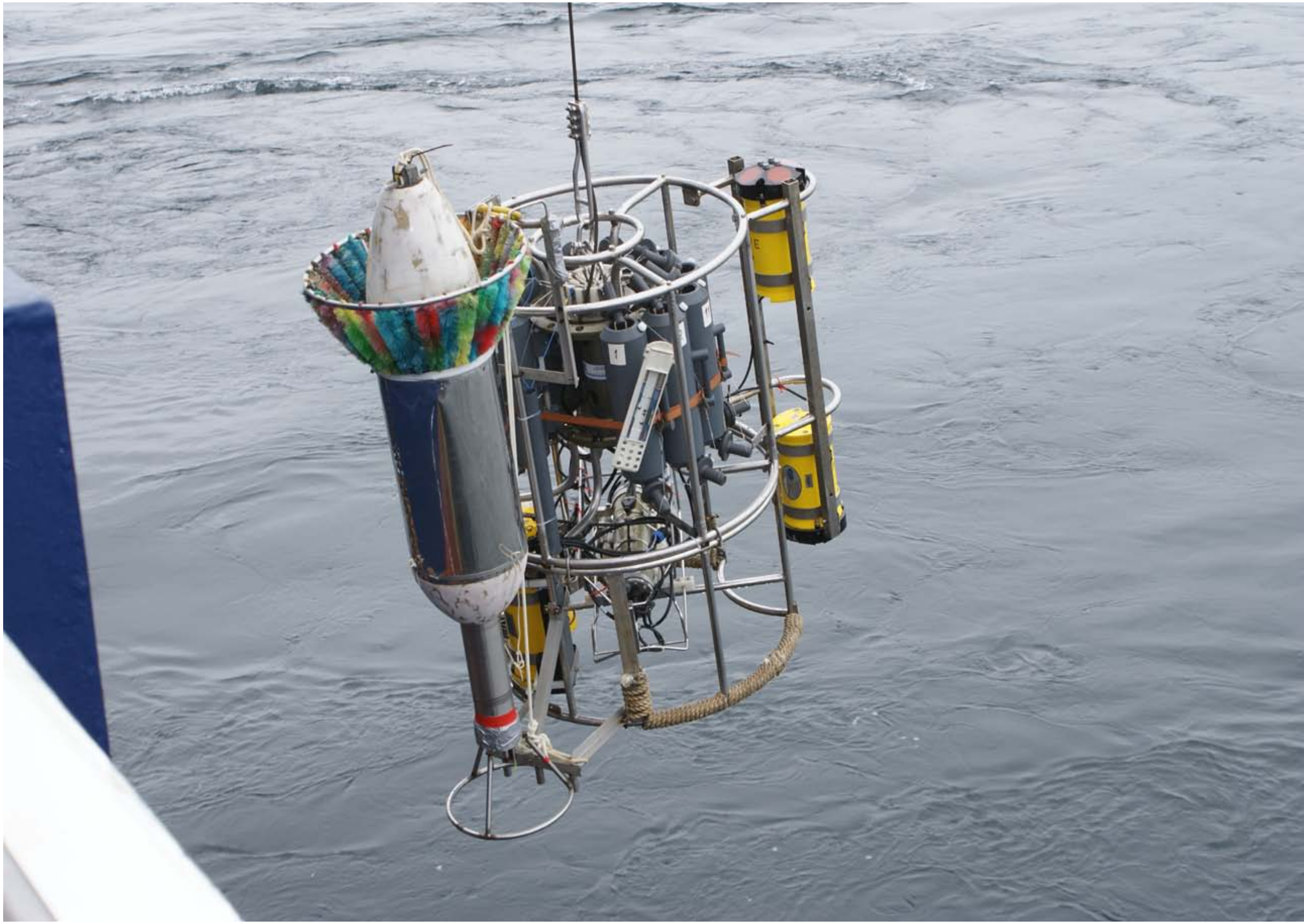
3) Мультипиксельные лавинные фотодиоды - МЛФД

A few proposals on carrying out common Russian-Greek (European) investigations with help of following techniques

- **1) The universal Complex using probes not using cables** for effective system of deep-water monitoring.

First step has been made – multi-channel probe (MSP- Micro-Structure Probe) with autonomous system of registration and variable floatation (next slide).

The Complex is suitable for arrangement on a small vessel!



2) The hydro-acoustical sea-ground antennas on the basis of digital hydrophones

- Single hydrophone and the cable antenna of IAP RAS on a reel (with a pressure sensor at its end)

Some characteristics of complex of antennas which could be used for hydro-acoustical telescope

- **Type of antenna – cable**
- **Deployment - ground, vertical**
- **Vertical antenna – N (16?) sections of 32 hydrophones**
- **Frequency range – up to 20KHz**
- **Distance between hydrophones – from 1 to 3 m**
- **Sensitivity of hydrophones - ~25 mV/Pa**
- **Depths – 2000 -100 m**
- **…..**

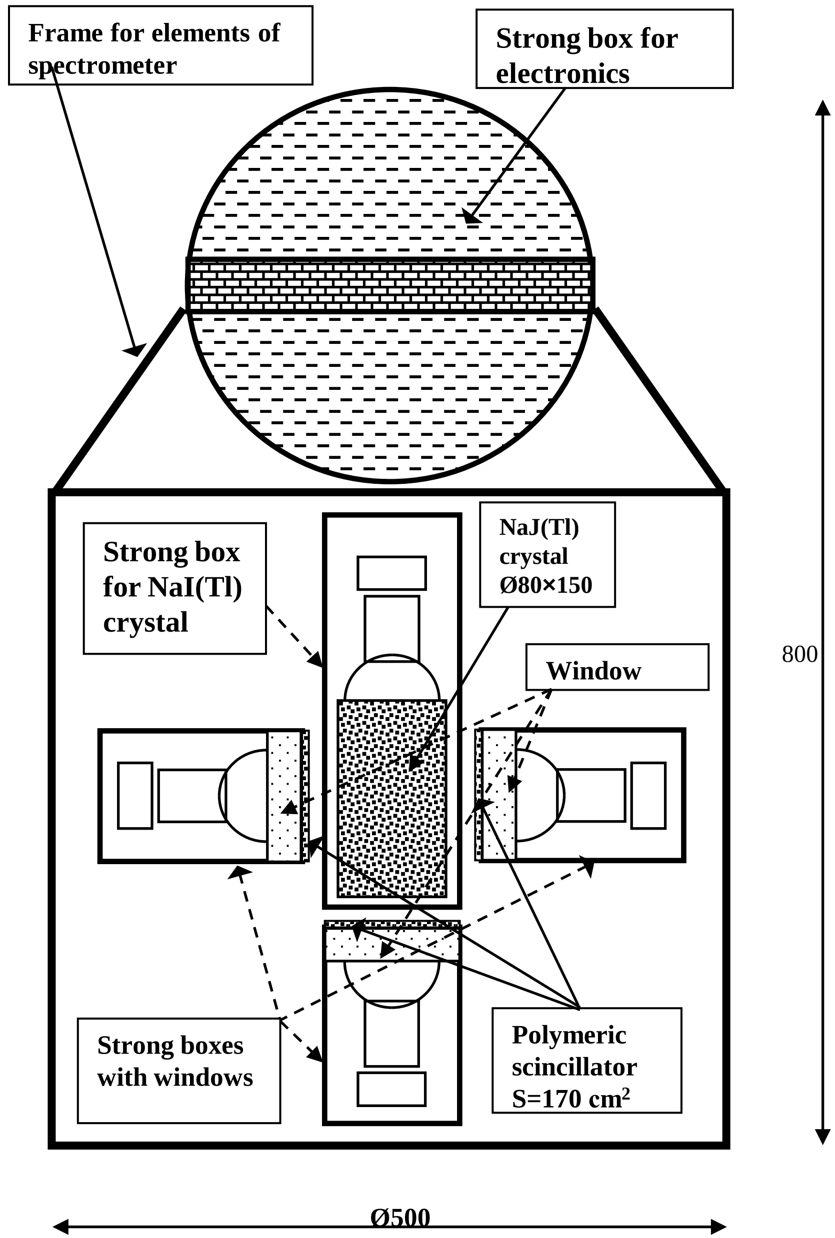
- **On a basis of such vertical antennas the architecture of a deep underwater hydro-acoustical array with the increasing volume aperture can be developed.**

Possibilities of oceanographic searches will also be increased !

3) A submersible scintillation spectrometer for definition of a composition and measuring concentration of the radionuclides dissolved in sea-water

- To decrease the background when spectra of γ -quanta are measured a scheme of coincidence of a signal from NaI (Tl)-crystal (detector of gammas) with a signal from thin-film polymeric scintillators, registering α - and β-particles, is used.
- Scintillation efficiency of an applied thin-film polymeric scintillators is 150 - 200 % of efficiency of the polystyrene scintillator.
- It does not change characteristics after monthly stay in sea-water.
- The laboratory sample of (αβ) - γ-coincidences spectrometer was built , the γ-background was suppressed approximately in 1000 times.
- The construction of submersible scintillation spectrometer is developed.

The scheme of submersible scintillation spectrometer



Conclusion 1

- Our suggestion – to organize simple but effective system of deep-water monitoring using available probes and small boats.
- First step has been made – **multi-channel probe (MSP-Micro-Structure Probe) with autonomous system of registration and variable floatation** was created.
- **The hydro-acoustical sea-ground antenna on the basis of digital hydrophones** with the inbuilt microprocessors for reception and selection of the weak signals is available for acoustical investigations and for development of acoustical neutrino telescope.
- **A laboratory sample of submersible scintillation spectrometer of (αβ) - γ- coincidences** for measuring of concentration of the radionuclides dissolved in sea-water (radium, radon, etc.) was developed.

- V.A. Matveev, **I.M. Zheleznykh**, P.I. Korotin, V.T. Paka, N.M. Surin/ “Alternative techniques for dear-water monitoring**”//**

  Nuclear Instr. & Methods in Phys. Res. A 626-627 (2011) S106-S108

- Collaboration Agreement for 2012 - 2014 between INR RAS, Moscow and the Institute of Nuclear and Particle Physics of the NCSR “Demokritus”, Athens

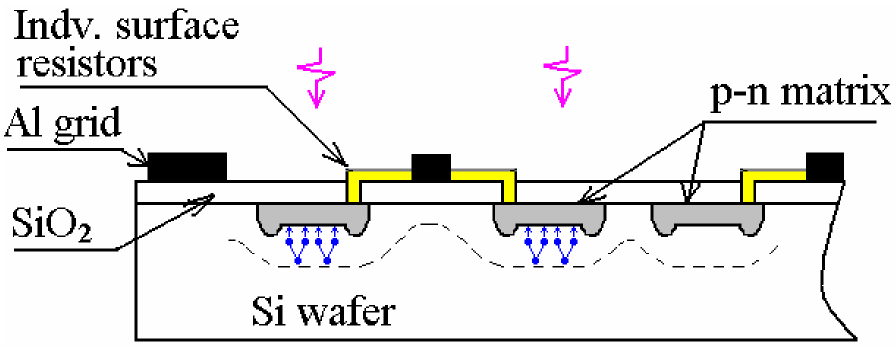
- R.D. Dagkesamanskii, V.A. Matveev, **I.M. Zheleznykh/** “Prospects of radio detection of extremely high energy neutrinos bombarding the Moon”// **Nuclear Instr. & Methods in Phys. Res. A 626-627 (2011) S44-S47**

- D. Besson**,**R. Dagkesamanskii, E. Kravchenko, I Kravchenko, **I. Zheleznykh/** “Tethered balloons for radio detection of ultra high energy cosmic neutrinos in Antarctica”// **Nuclear Instr. & Methods in Phys. Res. A662 (2012) S50-S53.**

. **I.M. Zheleznykh,** Z.Ya. Sadygov, B.A. Khrenov, A.F. Zerrouk./ Prospects of Application of Multi-pixel Avalanche Photo Diodes in Cosmic Rays Experiments**// Proc. 32nd ICRC, Beijing, 11-18 Aug. 2011.**

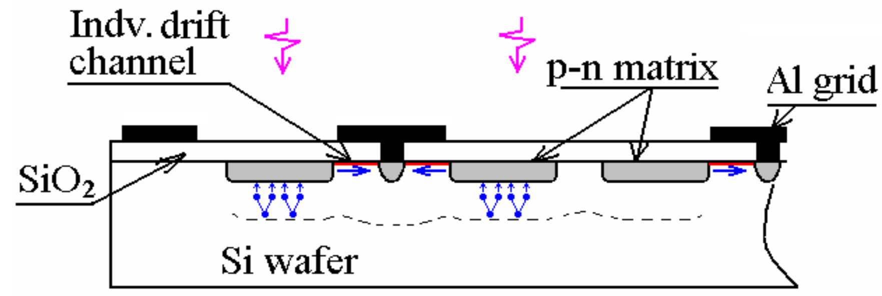
- **The development of new types of APDs with the local negative feedback – solid state analogs of multi channel PMT (Z. Sadygov et al.)- was supported in the frameworks of the Soviet DUMAND project led by M.A. Markov in 1981-1991.**
- **There was a long way of their development.**
- **Three advanced designs of MAPDs developed in INR/JINR after 1991, their advantages, restrictions were considered in [Z. Sadygov, A. Olshevski, I. Chirikov, I. Zheleznykh, A. Novikov. NIM, A567, 70 (2006).], for their schemes see next slide.**

The three advanced versions of AMPDs



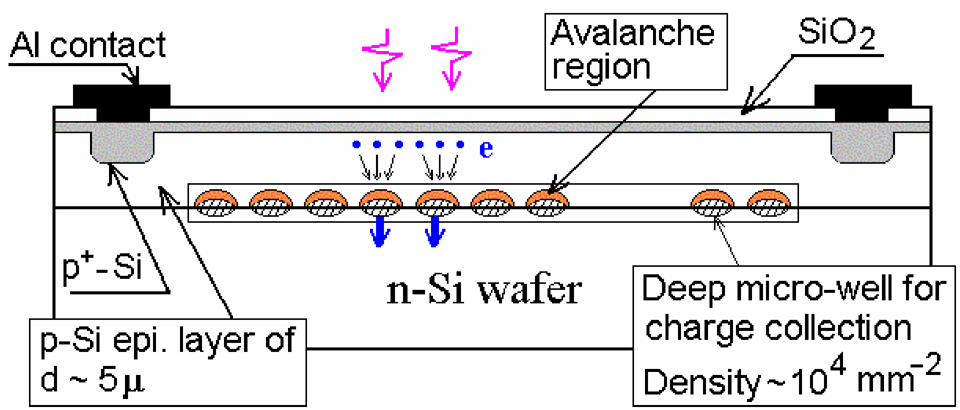
AMPD with individual surface resitors

Patent #2102820 from 10.10.1996.



AMPD with surface drift channel.

Patent #2086047 from 30.05.1996.



AMPD with deep micro-wells

Patent application #2005108324 from 24.03.2005.

Conclusion 2

- Выполнен Госконтракт (2010-2012) на тему: **«Разработка координатно-чувствительных сцинтилляционных детекторов гамма квантов, нейтронов и заряженных частиц на основе новейших мультипиксельных лавинных фотодиодов»**

  Исполнители ИЯИ РАН и НПО «Дубна –Детекторы»

- В 2012 г. заключен Договор о совместной научной, технологической и инновационной деятельности по разработке и применению МЛФД между ИЯИ РАН, ОИЯИ (Дубна), ИФ НАН (Баку), НПО «Дубна-Детекторы», “Zecotek Photonics Singapore”.
- Закуплен Educational Kit для студенческого практикума

CONCLUSION

«…Наконец, буквально на выходе находится нейтринная астрономия высоких энергий E > 10^12 эВ»

(В.Л. ГИНЗБУРГ «О НАУКЕ, О СЕБЕ И О ДРУГИХ», 2002 г.)