PROCEEDINGS OF SCIENCE
ONLINE ICRC 2021

Monitoring of optical properties of deep lake water

E. Ryabov[a*] **and B. Tarashansky**[a] **on behalf of the Baikal-GVD Collaboration**

(a complete list of authors can be found at the end of the proceedings)

[a] *Institute of Applied Physics ISU, b. Gagarina,20, Irkutsk, Russia*

E-mail: e_v_ryabov@mail.ru

We present the results of the one year monitoring of absorption and scattering lengths of light with wavelength 375–532 nm within the effective volume of the deep underwater neutrino telescope Baikal-GVD, which were measured by a device «BAIKAL-5D». The «BAIKAL-5D» was installed during the 2020 winter expedition at a depth of 1250 m. To carry out the optical measurements, we use a device with a shaded point-like isotropic light source having a spectral resolution of about 3 nm. A wide angle light receiver is moved by a stepper motor so that the distance between the receiver and the light source can vary from 0.9 m to 7.4 m. The absorption and scattering lengths were measured every week in 6 spectral points. The short-time variation of absorption length was estimated.

37th International Cosmic Ray Conference (ICRC 2021)
July 12th – 23rd, 2021
Online – Berlin, Germany

[*] Presenter

1. Introduction

The underwater neutrino telescope Baikal-GVD uses the photomultiplier tubes (PMTs) for collecting the Cherencov light emitted by the charged particles passing through effective volume of the detector. The array PMTs are buried in the deep water of Baikal lake. Therefore, knowledge of the optical properties of deep water of Baikal lake is essential for the operation of the Baikal-GVD as well as for the analysis of collected data. The scattering of light is quantitatively described by the so-called hydro-optical characteristics, absorption length $L_a(\lambda)$ and absorption coefficient ($a = 1/L_a(\lambda)$), whereas for the scattering of light, the relevant quantities are scattering length $L_b(\lambda)$, scattering coefficient ($b = 1/L_b(\lambda)$), and scattering function $\chi(\gamma,\lambda)$, with λ as the wavelength and γ as the scattering angle [1].

In this paper, we study the scattering and absorption of light with wavelenths in the range of 375–532 nm at a depth of 1250 m in Baikal lake using the data collected in the period from April 2020 to January 2021.

2. Device construction and measurement method

For in situ measurement of light scattering and absorption, the «BAIKAL-5D» instrument was developed. «BAIKAL-5D» was installed in the deployment area of the underwater neutrino telescope Baikal-GVD at a depth of 1250 m and provided the ability to monitor the absorption and scattering of water in the period from April 2020 to January 2021.

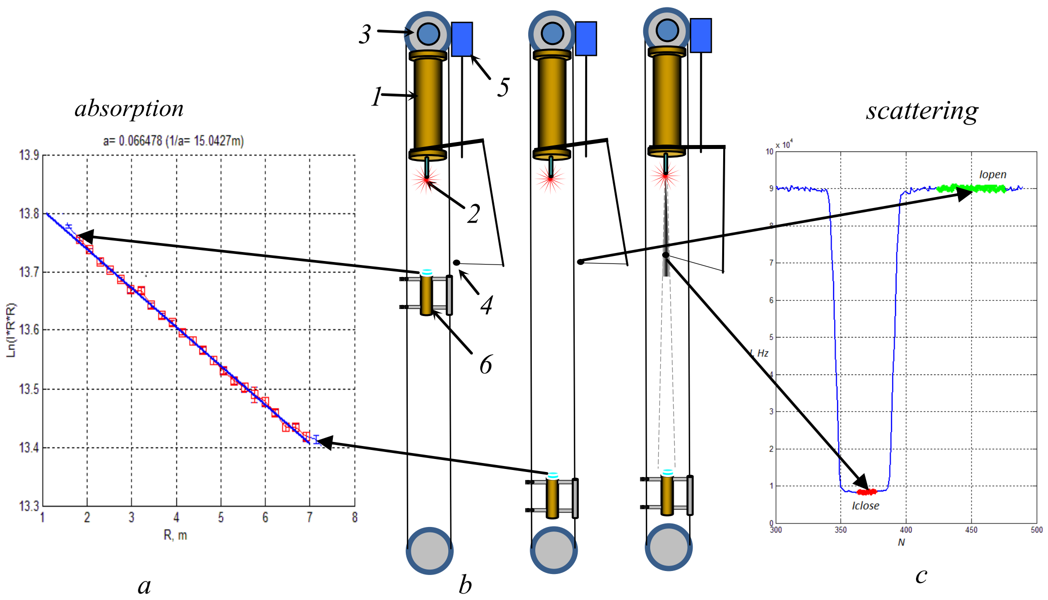

Figure 1: Layout of the «BAIKAL-5D» instrument with movable parts shown in three different positions (b), algorithm of measurement of absorption length (a) and scattering length (c).

The device (Fig. 1, b) has a hermetically sealed main housing (marked with 1), containing the electronics of the device and a monochromator inside, from the output slit of which the light enters through a light guide into a point-like quasi-isotropic emitter (marked with 2) mounted on the end cover of the housing. The spectral resolution of the light source is about 3 nm. On the main housing, a light receiver displacement drive (marked with 3) and a direct light source shading system (screen and stepper motor , marked with 4 and 5, respectively), providing an angular shadow size of 0.5° and 1°, are installed on the outside. The wide-angle receiver (marked with 6) in a separate housing is moved on thin cables so that the distance between the source and the receiver can vary in increments of 0.65 mm within 0.9-7.4 m. The device is controlled remotely from the shore computer, the program of which implements various measurement algorithms. To monitor possible changes in the geometry of the device due to underwater currents and string movements, a current sensor is installed above the device.

The methodological basis for measuring the absorption and scattering by such a device is discussed in detail in [2, 3, 4]. The algorithm used in this study for measuring the dependencies of absorption and scattering of light is as follows.

Measurement of absorption (Fig. 1, a). For a fixed wavelength, the dependence of the average intensity value I_k on the R_k (distance between the receiver and the source) is measured:

$$I_k = \frac{1}{m}\sum_{j=1}^{m} I_j(R_k), \quad R_k = R_{\min} + \frac{R_{\max} - R_{\min}}{n} k \,, k = [0;n] \,,\ n = 16 \div 32 \,,$$

where n - number of distance point, and m - number measurements in every point.
A linear approximation of the sequence of values $\{R_k\,, \ln(I_k R_k^2)\}$:

$$\ln(I_k R_k^2) = -aR_k + const \,,\ a = a(\lambda) = 1/L_a(\lambda)$$

is performed using the method of least squares over a distance range of 1.5÷7.0 m.

Measurement of scattering (Fig. 1, b). For the fixed wavelength and maximum distance R from the source to the receiver, the average intensity values from the open I_{open} and shaded I_{close} source are measured. The scattering length is calculated by the formula [3]:

$$b = 1/L_b(\lambda) = -\ln(1 - I_{close}/I_{open})/R \,.$$

2. Measurement results

The scattering length and absorption length were measured regularly once a week at six wavelengths: 375nm, 395nm, 430nm, 460nm, 490nm, 532nm.

From Figures 2 and 3, the following important features of absorption and scattering of lights are understood.

1. The trend for an increase in the absorption length was observed from April to the end of September and the subsequent exit to the plateau (Fig. 2). It is also possible to distinguish the minimum of absorption for all wavelengths on 21.10.2020.

2. The highest scattering of light was observed in the month of July (Fig. 3). It can be especially noted on 22.07.2020, when for all wavelengths the scattering length $L_b(\lambda)$ sharply decreased by 15-20% compared to that on 15.07.2020 and 29.07.2020. This point is also interesting because the count rate of the receiver with the source turned off-increased from

64Hz to 127 Hz. This can be most likely due to the arrival of a water layer with a different distribution of the suspension, which is also characterized by an increased glow, specific to this depth and time [1], and is recorded by the optical modules of the neutrino telescope.

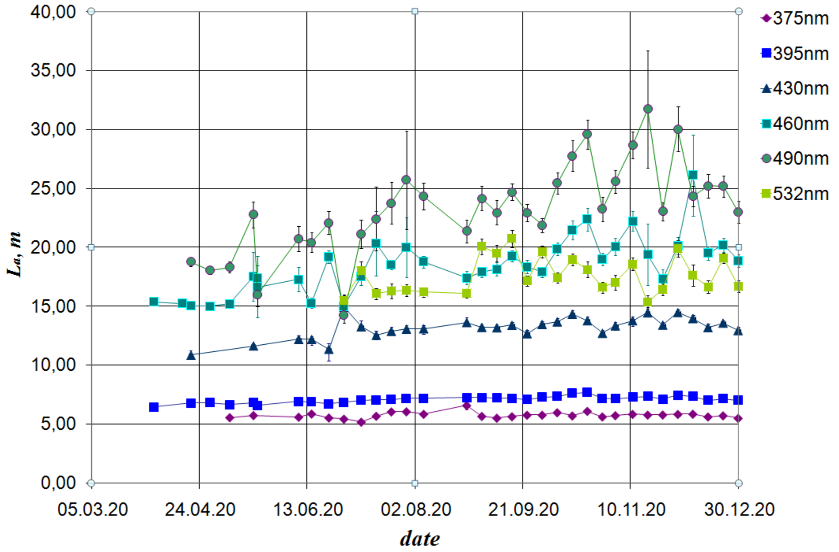

Figure 2: The time dependence of the absorption length during 2020 for six different wavelengths.

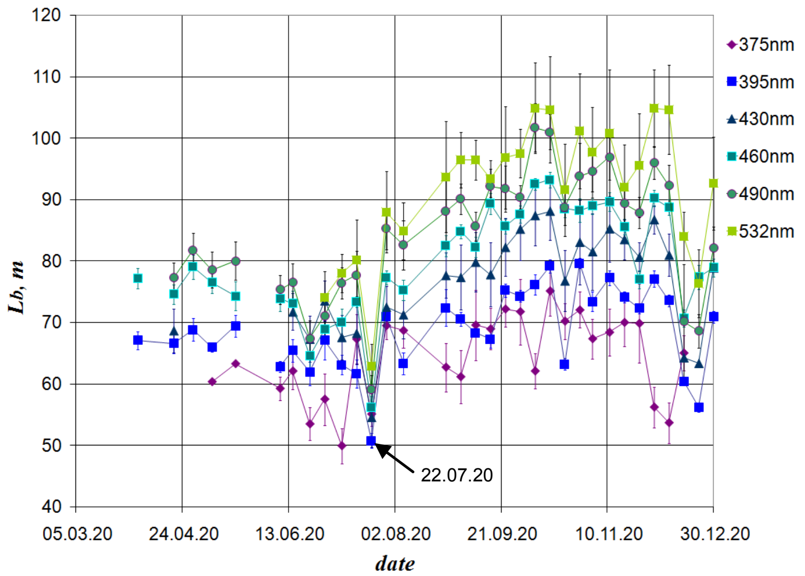

Figure 3: The time dependence of the scattering length during 2020 for six different wavelengths.

3. Minimum scattering occurring in mid-October.

The above measurements do not show short-time changes in absorption and scattering coefficients. A series of 10 measurements carried out in April and October with an interval of 1 hour with a single wavelength of 460 nm showed a scatter of values of coefficients not exceeding ±3% (the difference between the maximum and minimum values of absorption coefficients), which is comparable with the measurement error.

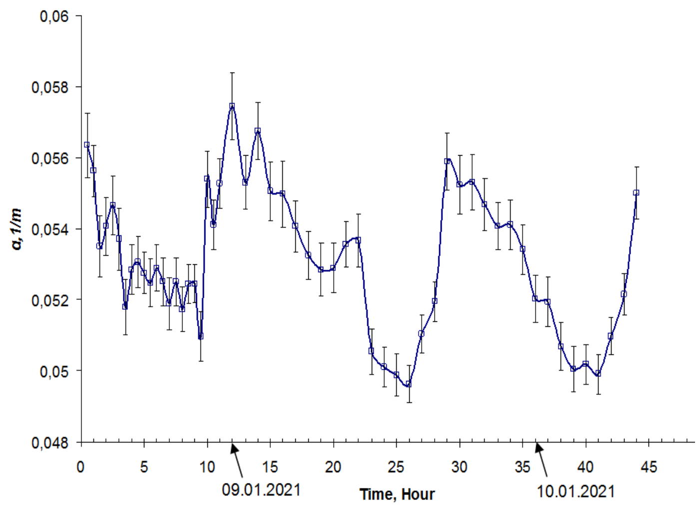

Figure 4: Short-time variation of absorption.

However, the hourly measurements of the absorption from 08.01.2021 to 11.01.2021 showed a change in the absorption coefficient in the range of 0.049-0.058 m^{-1} with a characteristic period of about 16 hours as shown in Fig. 4.

The spread in the values of the absorption coefficient exceeds the measurement error by a factor of 3 or more. In this case, the dependence of $\ln(I_k R_k^2)$ on R_k is linear in each measurement and differed only in the absorption coefficient. This fact greatly disfavors the probability of a large instrumental error of measurements.

The short-time variation of absorption in January and its absence in April and October, from our point of view, can be explained as follows. The existing measurements of currents and temperatures at the location and at the depth of the installation of the «BAIKAL-5D» (from 2019) indicate the development of the processes of transfer of water volumes in the period from November to January, which are especially clearly manifested during a storm. The period of these changes is also 15 to 17 hours. Unfortunately, there are no current and temperature data related to the time of the recorded changes in the absorption coefficient (the current sensor was damaged by a thunderstorm in July 2020). However, stormy weather during the measurement period suggests that currents and transfer of water volumes with different hydro-optical characteristics near the instrument could take place both in the vertical and horizontal planes. Under such conditions (currents and transfer of water volumes), the relative short-term change in the absorption coefficient can be estimated to be within ±10% and can be associated with the movement of water volumes with different hydro-optical characteristics.

3. Conclusion

In 2020, we managed to implement continuous monitoring in situ of absorption and scattering lengths of light with wavelength 375÷532nm within the effective volume of the deep underwater neutrino telescope Baikal-GVD using the «BAIKAL-5D» device without performing maintenance and adjustment procedures for 9 months. The data obtained make it possible to estimate long-term and short-term changes in absorption and scattering. The values of the absorption and scattering coefficients coincide with good accuracy with the previously obtained data [5] and the 2021 measurements by «BAIKAL-5D» №2 - the improved version of the device «BAIKAL-5D».

4. Acknowledgments

We acknowledge the support by the Ministry of Science and Higher Education of Russian Federation under the contract FZZE-2020-0017. The work was partially supported by RFBR grants 20-02-00400 and 19-29-11029. The CTU group acknowledges the support by European Regional Development Fund-Project No. CZ.02.1.01/0.0/0.0/16 019/0000766.

References

[1] Baicalogy: in 2 books.- Novosibirsk: Nauka, 2012.-Book 1.

[2] Bauer, D., Brun-Cottan, J.C. \& Saliot, A. 1971.Cah. Oceanogr. V.23. N.9. P. 841-858.

[3] A. Avrorin, et al., Asp-15—A stationary device for the measurement of the optical water properties at the NT200 neutrino telescope site, Nuclear Instruments &Methods In Physics Research A (2012), http://dx.doi.org/10.1016/j.nima.2012.06.035.

[4] O.N.Gaponenko, R.R.Mirgazov and B.A. Tarashanskii Reconstruction of the primary hydrooptical characteristics from the light field of a point source.//Atmos. Oceanic.Opt. 1996. V.9. No.8. P.667.

[5] Balkanov *et al.(* NEMO & Baikal Collaborations)) Simultaneous measurements of water optical properties by AC-9 transmissometer and ASP-15 inherent optical properties in Lake Baikal. //Nucl. Instrum. Meth. 2003. V. A298. P.231-239. e-Print Archive: astro-ph/0207553

Full Authors List: BAIKAL-GVD

V.A. Allakhverdyan[1], A.D. Avrorin[2], A.V. Avrorin[2], V.M. Aynutdinov[2], R. Bannasch[3], Z. Bardačová[4], I.A. Belolaptikov[1], I.V. Borina[1], V.B. Brudanin[1], N.M. Budnev[5], V.Y. Dik[1], G.V. Domogatsky[2], A.A. Doroshenko[2], R. Dvornický[1,4], A.N. Dyachok[5], Zh.-A.M. Dzhilkibaev[2], E. Eckerová[4], T.V. Elzhov[1], L. Fajt[6], S.V. Fialkovski[7], A.R. Gafarov[5], K.V. Golubkov[2], N.S. Gorshkov[1], T.I. Gress[5], M.S. Katulin[1], K.G. Kebkal[3], O.G. Kebkal[3], E.V. Khramov[1], M.M. Kolbin[1], K.V. Konischev[1], K.A. Kopański[8], A.V. Korobchenko[1], A.P. Koshechkin[2], V.A. Kozhin[9], M.V. Kruglov[1], M.K. Kryukov[2], V.F. Kulepov[7], Pa. Malecki[8], Y.M. Malyshkin[1], M.B. Milenin[2], R.R. Mirgazov[5], D.V. Naumov[1], V. Nazari[1], W. Noga[8], D.P. Petukhov[2], E.N. Pliskovsky[1], M.I. Rozanov[10], V.D. Rushay[1], E.V. Ryabov[5], G.B. Safronov[2], B.A. Shaybonov[1], M.D. Shelepov[2], F. Šimkovic[1,4,6], A.E. Sirenko[1], A.V. Skurikhin[9], A.G. Solovjev[1], M.N. Sorokovikov[1], I. Štekl[6], A.P. Stromakov[2], E.O. Sushenok[1], O.V. Suvorova[2], V.A. Tabolenko[5], B.A. Tarashansky[5], Y.V. Yablokova[1], S.A. Yakovlev[3], D.N. Zaborov[2]

[1] Joint Institute for Nuclear Research, Dubna, Russia, 141980

[2] Institute for Nuclear Research, Russian Academy of Sciences, Moscow, Russia, 117312

[3] EvoLogics GmbH, Berlin, Germany, 13355

[4] Comenius University, Bratislava, Slovakia, 81499

[5] Irkutsk State University, Irkutsk, Russia, 664003

[6] Czech Technical University in Prague, Prague, Czech Republic, 16000

[7] Nizhny Novgorod State Technical University, Nizhny Novgorod, Russia, 603950

[8] Institute of Nuclear Physics of Polish Academy of Sciences (IFJ PAN), Krakow, Poland, 60179

[9] Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia, 119991

[10] St. Petersburg State Marine Technical University, St. Petersburg, Russia, 190008