nuclide abundance is plotted as a function of the relative baryon-to-photon number density ratio n_B/n_γ. Figure 5a demonstrates the value of (D/H) measured in quasar spectra from absorption lines of D I/H I atoms and from HD/H_2 molecular lines (see [4] for data and references). In Fig. 5b, the results of measurements of the relative abundance of relic nuclides ^{2}D, ^{3}He, ^{4}He, and ^{7}Li are compared with theoretical calculations and with the n_B/n_γ ratio derived from the analysis of angular fluctuations of the CMB temperature [13].

With the obtained value of (D/H), the BBN theory implies the baryon-to-photon number density ratio $n_B/n_\gamma = (5 \pm 1) \times 10^{-10}$ [4]. In calculating the kinetics of the primordial nucleosynthesis, we have used a modified code developed in [14, 15]. According to the standard cosmological model, the n_B/n_γ ratio should not have changed from BBN times to the present day, i.e., it is assumed that baryons have not decayed and CDM particles have not been converted into baryons. At present, the CMB photon number density corresponding to the temperature $T_0 = 2.726$ K is $n_\gamma = 411$ cm^{-3}. Therefore, the mean baryon number density must be $n_B(0) = (2.1 \pm 0.4) \times 10^{-7}$ cm^{-3}. But in contrast to the BBN epoch when the medium was almost homogeneous, the present-day space matter distribution is highly inhomogeneous, and hence $n_B(0)$ is the mean value in a large space region of the order of 100 Mpc. The obtained value $n_B(0)$ corresponds to $(3.7 \pm 0.8)\%$ of the critical density (for the assumed Hubble constant $H_0 = 70$ km s^{-1} Mpc^{-1}). This is consistent within error with the value obtained from the CMB temperature fluctuations [13].

4. Conclusion

For the first time, a cloud of cold rarefied gas containing H_2 and HD molecules was discovered at a large cosmological distance. The elemental abundance and physical conditions in the cloud that existed 12 Gyr ago have been studied. The column density ratio HD/H_2 in the cloud is shown to be much higher than the present-day value measured in interstellar clouds of our Galaxy [4].

The relative isotopic abundance D/H in this cloud was measured by a novel (independent) method from the column density ratio of HD/H_2 molecules using molecular cloud models [10–12]. The derived value $D/H = (3.6^{+1.9}_{-1.1}) \times 10^{-5}$ and the standard BBN model allowed an independent determination of the mean baryonic density at the present time $\Omega_B \equiv \rho_B/\rho_{cr} = (3.7 \pm 0.8)\%$ [4].

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Cosmic gamma-ray bursts and gamma repeaters studies with Ioffe Institute Konus experiments

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This report presents the results of the study of cosmic gamma-ray transients, performed for many years by the Ioffe Institute onboard interplanetary space missions and near-Earth satellites. These transients have been found in several classes: many of the basic characteristics of cosmic gamma-ray bursts (GRBs), such as their temporal profiles and energy spectra, and the first all-sky map of their source distribution on the celestial sphere, were determined using early Konus experiments onboard the Venera 11, 12, 13, and 14 deep space vehicles. As a result of the observations of the giant flare on 5 March 1979 and the discovery of a series of short gamma-ray bursts, also determined to have a common source and to come from the same source direction as the giant flare, this new class of rare astrophysical phenomena was discovered. Somewhat later, these were named soft gamma repeaters (SGRs). In the subsequent Konus and Helicon experiments, studies of cosmic gamma-ray bursts and of soft gamma repeaters were continued, new SGR sources were found, and other giant SGR flares were also found. GRBs come from very distant cosmological sources, but SGR sources, analyzed in detail, have been localized in our Galaxy and in its satellite, the Large Magellanic Cloud (LMC). Recently and most notably, Konus measurements have been central in finding SGRs in the nearby galaxies M81 and M31, far outside our own Milky Way system. In the modern epoch of multi-wavelength studies of cosmic gamma-ray bursts, the joint Russian–American Konus–Wind experiment, which has already been operating for more than 15 years, provides important and often unique data regarding the various characteristics of these diverse types of transient gamma-ray emissions in the 10 keV to 10 MeV energy range.

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The nature of cosmic gamma-ray bursts as extremely explosive releases of electromagnetic energy has been the focus of astrophysicists' attention since soon after their discovery in 1967–1973 by the U.S. Vela satellites [1]. One of the earliest confirmations of the discovery of this new phenomenon was provided by observations collected by the Ioffe Institute using data from the Kosmos 461 satellite [2]. Later, an important breakthrough in the studies of gamma-ray bursts was made possible by the four Konus experiments carried out by the Ioffe Institute onboard the Venera 11 to 14 deep space missions in 1978 to 1983. These missions were among the first to make measurements of the various observational properties of gamma-ray bursts, which still constitute the basis of modern concepts in GRB research. In particular, Konus observations of the temporal structures of gamma-ray bursts were central to the discovery of the existence of a separate class of short bursts, demonstrating the so-called 'bimodal' duration distribution. In addition, the array of Konus detectors, each having anisotropic sensitivity, could be used along with the intersatellite triangulation method for a stand-alone determination of approximate source directions. It was for the first time shown with good statistical accuracy that their distribution over the celestial sphere is random (Fig. 1) [3, 4]. Later, this result was confirmed with an even larger number of events in the well-known BATSE experiment onboard NASA's Compton Gamma-Ray Observatory [5].

An extremely interesting and totally unexpected result was that a new class of gamma-ray transients was found using the Konus experiments onboard the early Venera deep-space missions. Occurring very rarely, yet found to repeat at random, these were later named soft gamma repeaters. These sources exhibit two kinds of bursting activity: the first is the emission of soft, repeated bursts with a duration ~ 0.1 s and an isotropic energy release $\sim 10^{39}$ to 10^{41} erg. The occurrences of the bursting activity of SGRs are highly nonuniform in time; the sources are predominantly in the quiescent state, which may continue for years, but is interrupted by periods of intense reactivation, with several to several hundred events at a time. The other, far more impressive kind of repeater activity consists of even more rare giant flares with the peak power comparable to the luminosity of quasars ($10^{45}-10^{47}$ erg s^{-1}). The relation of the flares to soft gamma repeaters was first manifested with the observation on 5 March 1979 of a giant outburst of hard X-ray and soft gamma radiation. Its source direction was shown by a network of international spacecraft to be that of a supernova remnant in the Large Magellanic Cloud at the distance 55 kpc; independently, its source was shown by Konus data to precisely agree with the source of the first soft gamma repeater series. The flare profile consisted of a narrow, exceedingly intense, initial emission peak with a harder energy spectrum, followed by a weaker decay with a softer spectrum, which exhibited pulsations having a period of 8 seconds for several minutes (Fig. 2a, [6, 7]). Already on the next day, the first of the repeated events from the same source direction was recorded by Konus instrumentation. Over several years, 17 repeated bursts of this kind were detected from SGR 0526-66 (Fig. 2b, [8]). The giant flare of 5 March 1979 had been a unique astrophysical event for nearly 20 years when, on 27 August 1998, a giant flare was detected by many spacecraft, with the source agreeing with that of SGR 1900+14. It was shown with the Konus–Wind experiment and the Ulysses mission to have the same specific features as the first repeater, SGR 0526-66. A third, even stronger flare of this kind was observed on 27 December 2004 from SGR 1806-20. According to the commonly accepted concept, soft gamma repeaters are young ($\sim 10^3$ to 10^4 yr) neutron stars with rapidly slowing rotation rates and super-strong ($\sim 10^{15}$ G) magnetic fields.

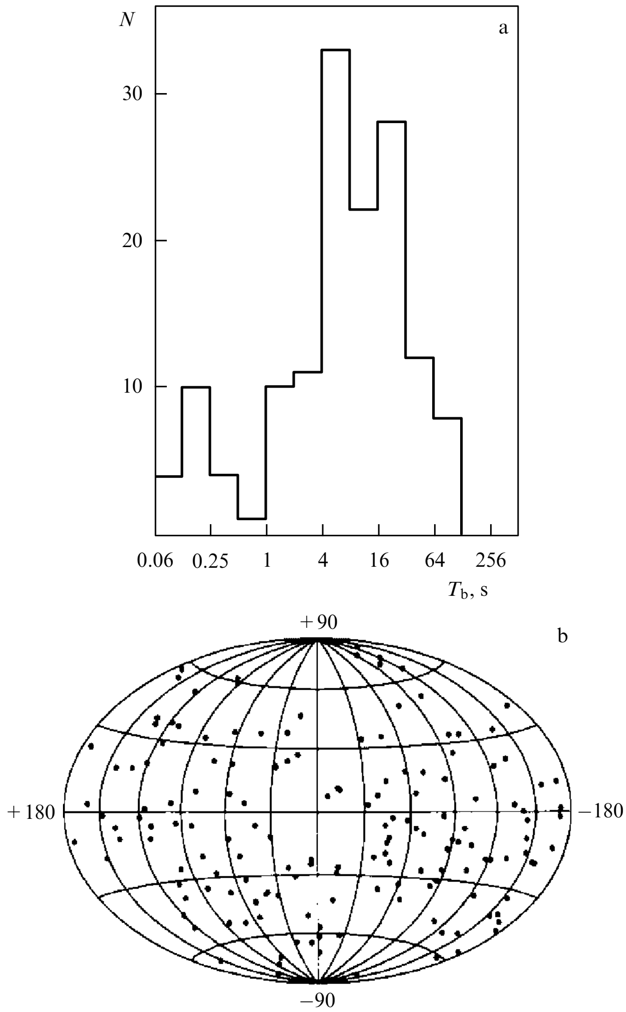

Figure 1. The duration distribution of gamma-ray bursts and the first statistically meaningful distribution of GRB sources over the celestial sphere, determined by the Konus experiments onboard the Venera 11 to 14 interplanetary missions from 1978 to 1983.

A new and important chapter in the research of cosmic gamma-ray bursts and soft gamma repeaters at the Ioffe Institute is associated with a joint Russian–American experiment with the Russian Konus scientific instrument onboard the U.S. Wind spacecraft. The deep space trajectory of the Wind spacecraft is actively adjusted to have an apogee as great as a 5-light-second distance. Remote from Earth and the Moon, its exposure to the entire celestial sphere is exceedingly favorable for studies of unpredictable and transient sources. Two high-sensitivity scintillation detectors of the Konus–Wind gamma-spectrometer permanently view the entire celestial sphere, such that no event important to the astrophysics of gamma-ray bursts and gamma repeaters has yet been missed by the Konus–Wind experiment throughout the 15 years of its successful and uninterrupted operation. These advantages of the Konus–Wind experiment were clearly demonstrated by its observation in 1998 of a contrast

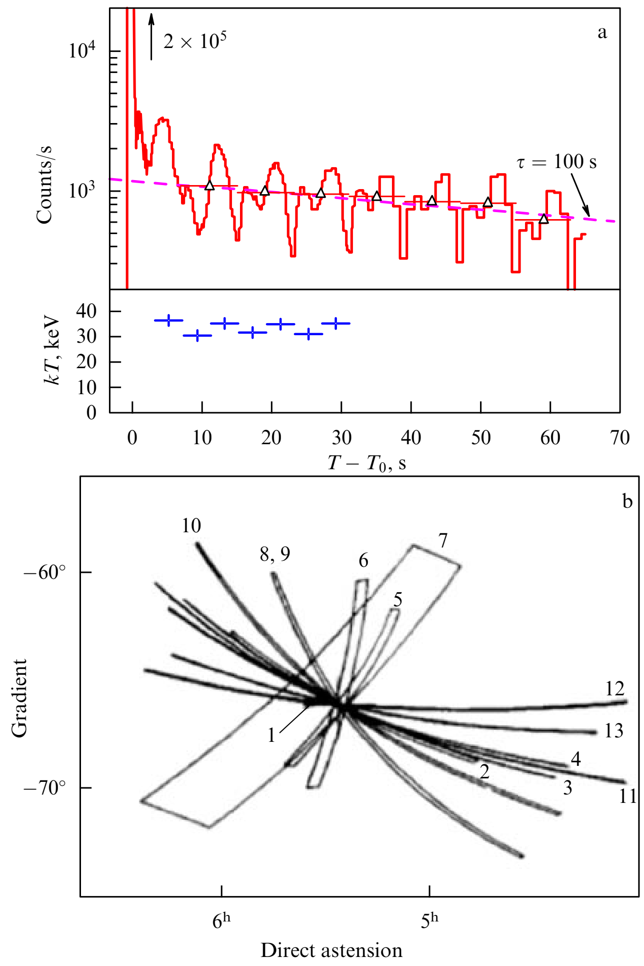

Figure 2. The giant flare on 5 March 1979 and repeated bursts from SGR 0526-66, measured by the Konus instrument onboard the Venera 11 and 12 interplanetary missions.

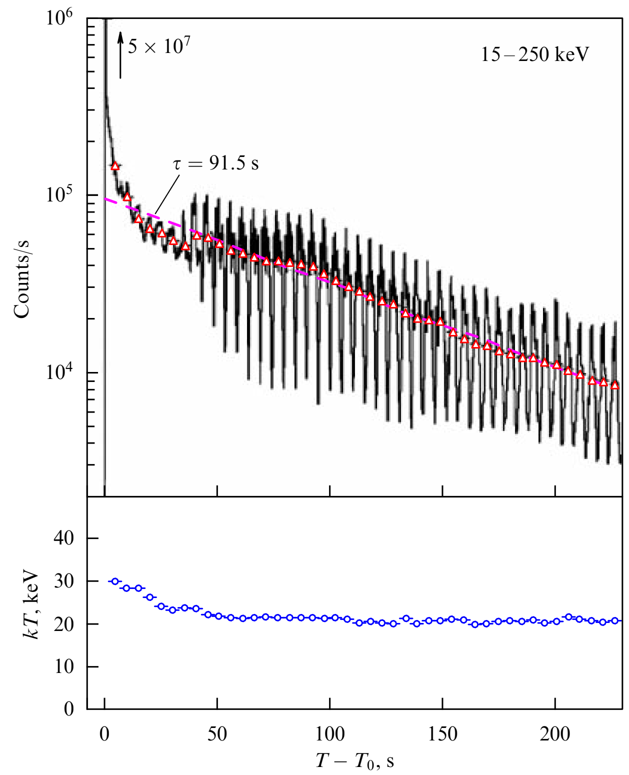

Figure 3. The giant flare from SGR 1900+14 on 27 August 1998, found by the Konus–Wind instrument.

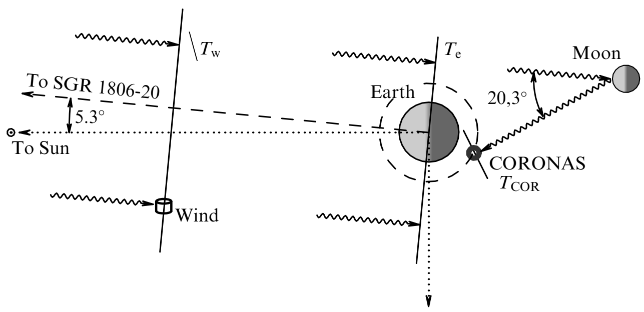

Figure 4. The reflection of the initial pulse of the giant flare from SGR 1806-20 by the Moon, and its detection by the Helicon instrument onboard the CORONAS-F spacecraft.

between two of the rarest celestial gamma-ray transients. The first — exceedingly powerful but having no pulsating tail — was observed on 18 June from the recently discovered SGR 1627-41 [9]. The second was a giant flare on 27 August from SGR 1900+14 (Fig. 3, [10]), in which all the typical indications of this phenomenon are observed: a short, exceedingly intense initial pulse of gamma radiation followed by a ≈ 500 s decay that pulsated with a period characteristic of a neutron star.

The photon counting rate of gamma rays in the initial pulse of a giant SGR flare is always so great that the sensitive detectors of the instrument are fully overloaded ('saturated'), such that precise measurements of the characteristics of the initial pulse become difficult and only rough lower-bound estimates are possible. For the most powerful of the recorded bursts, which came from the SGR 1806-20 source on 27 December 2004, the Konus–Wind detector was evidently saturated for over 1.5 s. However, the situation was fortunately quite favorable for the observation of a most unusual aspect of this event, due to the simultaneous measurements made using the Helicon spectrometer onboard the CORONAS-F orbiting solar observatory. This instrument, also from the Ioffe Institute, is identical to that of Konus–Wind. The positions of the spacecraft at the time of detection of this burst are shown schematically in Fig. 4 [11]. The detectors of the Helicon instrument were screened by Earth from direct exposure to the initial pulse of the giant burst from the gamma repeater, but clearly recorded its reflection from the Moon surface. This reduction in intensity allowed, for the first time, reliably reconstructing the temporal profile of the initial pulse of a giant burst from a gamma repeater (Fig. 5 [11]) and determining its energy parameters: the full isotropic energy release of 2.3×10^{46} erg and the peak luminosity 3.5×10^{47} erg s^{-1}. The research on the 27 December 2004 flare was the first example of studying Moon-reflected X-ray and gamma radiation coming from a source outside the Solar System.

The observations of giant flares from SGR 1900+14 and SGR 1806-20 have revived interest in a suggestion originally made in 1981–1982 by Mazets and Golenetskii [3] that some short, hard gamma-ray bursts that seem to be cosmic GRBs may instead be the initial pulses of giant flares from extragalactic SGRs. With the energy parameters of the

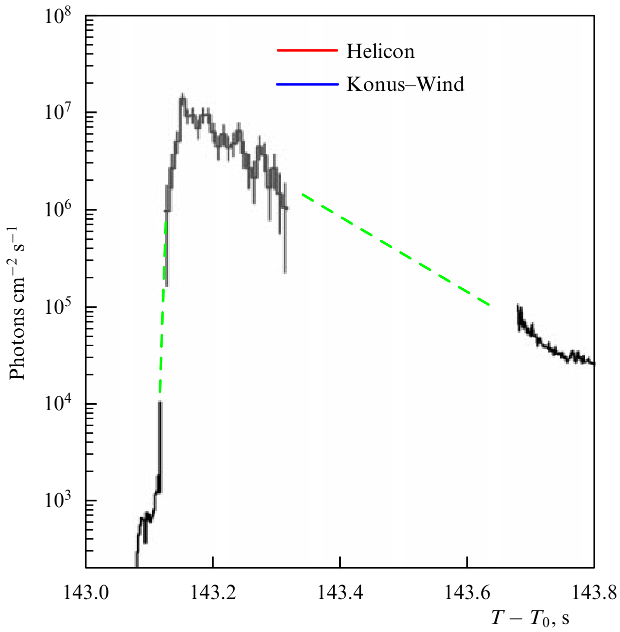

Figure 5. The temporal profile of the initial pulse of the giant flare from SGR 1806-20, reconstructed from Konus–Wind and Helicon data.

initial pulse of the giant flare from SGR 1806-20 having been determined, it became possible to estimate the maximum distance at which flares of this kind can be recorded: for modern detectors with wide field of view, this distance is 30 to 50 Mpc. The available data on giant flares from the known Galactic SGRs can be used to find the expected temporal and spectral characteristics of a short gamma-ray event that might instead be the detection of a flare from another galaxy. Such a burst must have the form of a single pulse with a steep leading edge and duration from approximately 5 to 15 ms, having an exponential decay with a time constant ≈ 50 to 70 ms and the total pulse width ~ 200 to 300 ms. The energy spectrum of the emission must be rather hard in the initial part, rapidly evolving to become noticeably softer by the end of the pulse. An analysis of the characteristics of short bursts on the basis of the Konus–Wind data demonstrated that the fraction of events with the above characteristics does not exceed several percent of the total number of short bursts.

On 3 November 2005, Konus–Wind recorded the short and hard bright gamma-ray burst GRB 051103. [12]. Localization of this event by the Interplanetary Network, which includes most of the experiments observing gamma-ray bursts, demonstrated that its source lay close to the M81 group of galaxies, situated at a distance ≈ 3.6 Mpc from Earth. The light curve of the event, recorded with a 2 ms time resolution, displayed a single pulse with a steep leading edge $\leqslant 6$ ms and exponential decay in approximately 55 ms. The event had the total duration 170 ms. The time variation of the radiation hardness pointed to a pronounced softening of the emission spectrum. Among the three detailed energy spectra recorded with the accumulation time 64 ms, only the first contained a high-intensity hard component with energies up to 10 MeV. The results of studies of matter distribution in the M81 group of galaxies, furnished by optical, X-ray, and radio astronomy, were compared with the localization data for the source of this gamma-ray burst. This source direction and the details of the event measurements support its identification as a giant flare from a gamma repeater located in the M81 group of galaxies. The flare energy would be $\sim 7 \times 10^{46}$ erg in this case, which is quite comparable to the energy of the giant flare in SGR 1806-20 [11].

Another intense gamma-ray event with a short duration and a hard spectrum was recorded by the Konus–Wind experiment on 1 February 2007 (Fig. 6a, [13]); it had the highest intensity in the entire history of gamma-ray extragalactic transient observations. The temporal profile of the event is a narrow pulse with a leading edge ≈ 20 ms and a more gently sloping decay, with the total duration ~ 180 ms. The burst exhibited a strong spectral evolution, with the hard emission component observed within the first 80 ms. The source localization region, determined by the Interplanetary Network and shown in Fig. 6b, coincides with the outer arms of the Andromeda Galaxy (M31), situated at the distance ≈ 780 kpc. A detailed analysis of the observations of the Andromeda Galaxy by IR, UV, and X-ray space telescopes and a comparison of the characteristics of GRB 070201 with those of the previously observed giant flares from gamma repeaters argue convincingly that this event is a giant flare from a gamma repeater in the Andromeda Galaxy. The sources of the events on 3 November 2005 and 1 February 2007, as the first soft gamma repeaters from beyond our local galaxy group, were designated SGR 0952+69 (M81) and SGR 0044+42 (M31) [13].

The Konus–Wind experiment revealed a strong spectral variability of a new source of soft repeated bursts, SGR 0501+4516, discovered in August 2008 by the BAT telescope onboard NASA's Swift spacecraft. Five bursts from the new gamma repeater were recorded and analyzed in detail by the Konus–Wind gamma spectrometer [14]. An important feature of this new repeater is the strong correlation between the emission hardness in the course of repeated bursts and the emission intensity. A correlation of this kind had been observed previously only for the SGR 1627-41 gamma repeater [9]. Among the recent results obtained in the Konus experiments, we note the discovery of a new source of soft repeated gamma-ray bursts, the SGR 0418+5729 gamma repeater, on 5 June 2009 [15]. This study was carried out in joint observations with GBM detectors of the Fermi observatory, the Konus-RF spectrometer of the CORONAS-Photon observatory, and the BAT telescope of the Swift observatory.

Owing to its high, omnidirectional sensitivity and location far from Earth, providing the optimum situation for observations of the entire sky at all times, the Konus–Wind experiment is a unique source of information about the temporal and spectral characteristics of gamma-ray events in the energy range from 10 keV to 10 MeV. These data constitute an essential element of modern multi-wavelength studies of gamma-ray transient events involving spacecraft with a network of ground-based optical and radio telescopes. Konus–Wind observations are thus in wide demand. Thanks to rapid and accurate localization of gamma-ray transient sources by the BAT telescope at the Swift observatory, studies by a global network of ground-based telescopes are commenced, in fact, within seconds to tens of seconds after the beginning of an event. Figure 7 shows the gamma-ray light curve from the Konus–Wind experiment and that obtained in the visible spectral range by TORTORA (Special Astrophysical Observatory, Russian Academy of Sciences) and the Polish Pi of the Sky telescopes for the famous GRB 080319B burst. Its luminosity in the optical spectral range reached the

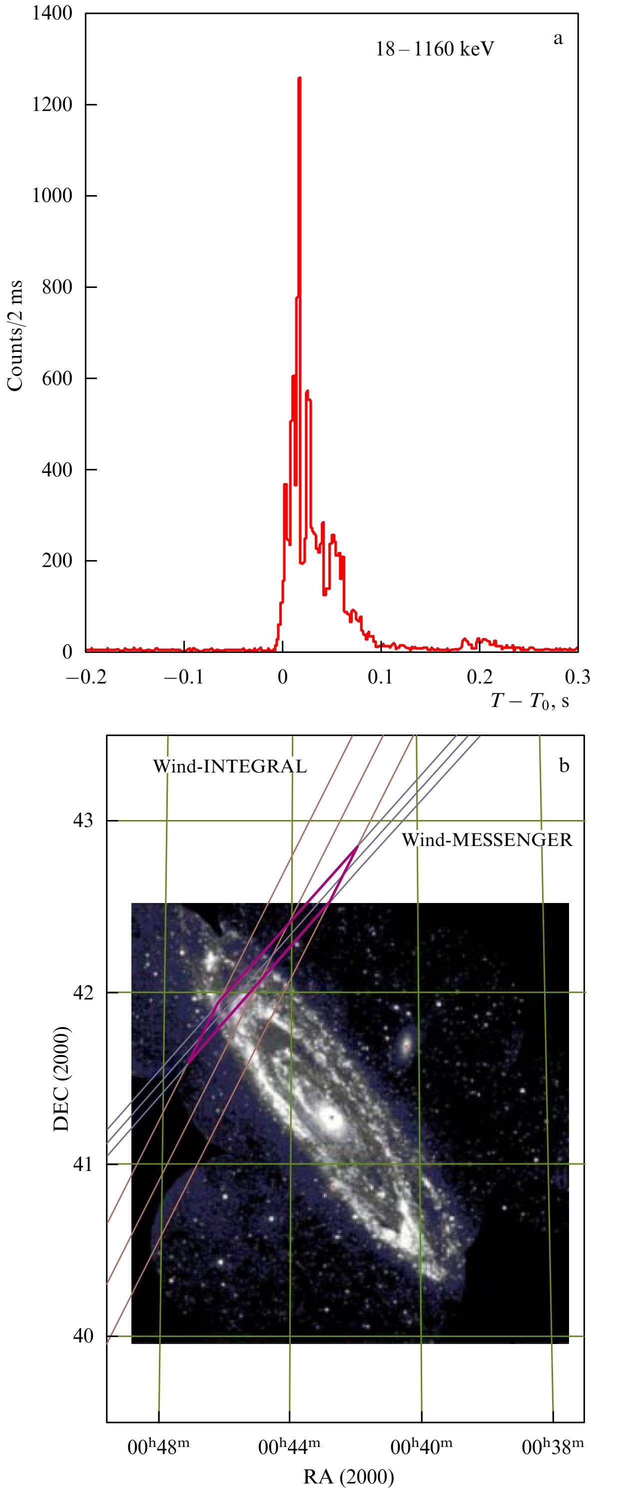

Figure 6. GRB 070201, a giant flare from the SGR 0044+42 gamma repeater in the Andromeda Nebula: the light curve from Konus–Wind data and the source localization by the Interplanetary Network.

apparent magnitude 5.5. Multi-wavelength studies demonstrate that the optical and gamma emissions of this burst begin and end at the same time, which strongly suggests that they originate from the same physical region [16].

In conclusion, we emphasize that the Konus instruments developed at the Ioffe Institute continue to be reliable and adequate to the task of studying cosmic gamma-ray bursts. Owing to the importance, quality, and completeness of the

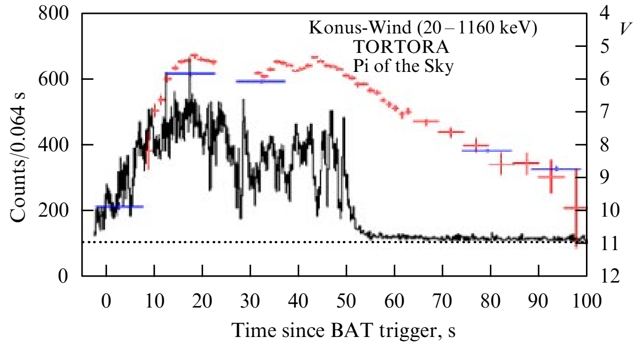

Figure 7. Optical and gamma emission of the GRB 080319B event, determined by Konus-Wind, TORTORA, and Pi of the Sky data [16].

information obtained, the Russian–American Konus–Wind experiment has advanced to the forefront of research into extremely explosive phenomena in the Universe. During the 15 years of uninterrupted observations, more than 3500 cosmic gamma-ray bursts have been detected and analyzed, and the bursting activity of all the known gamma repeaters has been studied. An earlier summary of data on gamma repeaters obtained with the Konus experiments can be found in "Konus Catalog of SGR Activity: 1978 to 2000" [17]. Printed and electronic versions of a second catalog of data obtained in observations of gamma repeaters in Konus–Wind, Konus, Helicon, and Konus-RF experiments are in preparation. This catalog covers the observation period from 1994 to 2009 and contains information about all the known soft gamma repeaters and giant SGR flares obtained from all the identical Konus instruments. Another summary of observational data regarding only the short gamma-ray bursts detected from 1994 to 2002 is contained in the electronic catalog at www.ioffe.ru/LEA/shortGRBs/Catalog/. Printed and electronic versions of the catalog of short bursts from 1994 to 2009 are also being prepared.

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Discovery of the fast optical variability of GRB 080319B and the prospects for wide-field optical monitoring with high time resolution

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1. Introduction

The systematic investigation of the night sky variability on a subsecond time scale is an important but still largely unaddressed issue. That the observations of this kind are necessary for the search for transient objects with a priori unknown localization and for their study was already emphasized by Bondi [1]. Investigations have been pursued in this area [2, 3]; but owing to technical difficulties, they either were able to attain a high temporal resolution on the level of several dozen microseconds in monitoring $5'-10'$ fields or used a temporal resolution of 5–10 s for wide $(20°-30°)$ fields. The currently operating wide-field monitoring systems, like WIDGET [4], RAPTOR [5], BOOTES [6], and 'Pi of the Sky' [7], have large fields of view with relatively good detection limits, but low temporal resolution, which hinders their use for detecting fast transients.

We give several examples of these transients: UV Cet-type stellar flares with rise times 0.2–0.5 s [8], 30% of gamma-ray bursts that last less than 2 s, while individual details of their light curves may be as short as 1 ms [9]. Also of substantial interest are very fast meteors, which are conceivably produced beyond the Solar System [10].

One further problem that invites conducting regular wide-field observations with a high temporal resolution is the monitoring of circumterrestrial space. The trajectories of a large number of satellites, as well as of a great quantity of small particles of space debris, change rather quickly and the speeds of these objects are quite high, making their observation by conventional techniques a very difficult task.

Since the late 1990s, we are developing the strategy of optical monitoring with a high temporal resolution of celestial sphere regions comparable in size to the field of view of spaceborne gamma-ray telescopes. Initially, we planned to use instruments with large mirrors of relatively low quality [11, 12], for instance, Cherenkov telescopes and solar concentrators involving photomultiplier arrays with a temporal resolution as high as several microseconds. But more recently, we decided in favor of a project involving a wide-field camera with a lens of a relatively small diameter, an image intensifier (II) for the effective shortening of the focal length, and a fast low-noise CCD (charge-coupled device). A prototype of this system, FAst Variability Optical Registrator (FAVOR), put into operation in 2003, is located near the 6-meter BTA (Big Telescope Alt-azimuthal) of the Special Astrophysical Observatory of the Russian Academy of Sciences [13, 14]. The TORTORA (Telescopio Ottimizzato per la Ricerca dei Transienti Ottici RApidi) camera of similar design [15], which was installed on the mounting of the Rapid Eye Mount (REM) robotic telescope in the La Silla Observatory (ESO, European Southern Observatory, Chile) in 2006, makes up a two-telescope TORTOREM complex together with REM [17]. It was precisely this camera that discovered and enabled a detailed study of the optical emission of the brightest ever gamma-ray burst GRB 080319B [18–20].

In this report, we describe the design and special implementation features of the TORTORA camera and outline several results of its operation, including a comprehensive analysis of the data on the GRB 080319B burst. Also discussed is the project of a next-generation wide-field monitoring system capable not only of discovering much weaker transients but also of performing their multicolor photometry and polarimetry.

2. Description of the wide-field cameras FAVOR and TORTORA

The parameters of the FAVOR and TORTORA cameras are compared with those of other presently existing wide-field monitoring systems in Table 1. It follows that only the FAVOR and TORTORA cameras have a high temporal resolution and a relatively large field of view.

The structure of the TORTORA camera is diagrammed in Fig. 1, its parameters are collected in Table 2, and its image is given in Fig. 2. The instrument consists of the main

Table 1. Main optical wide-field monitoring systems currently operating.

Designation	Field of view, deg	Resolution, s	Detection threshold
WIDGET	62×62	5	10^m
RAPTOR A/B	40×40	60	12^m
RAPTOR Q	180×180	10	10^m
BOOTES	16×11	30	12^m
BOOTES-AllSky	180×180	30	10^m
'Pi of the Sky'	33×33	10	11.5^m
AROMA-W	25×35	5–100	10.5^m-13^m
MASTER-VWF	20×21	5	11.5^m
MASTER-Net	30×30	1	9^m
FAVOR*	16×24	0.13	$10^m-11.5^m$
TORTORA*	24×32	0.13	$9^m-10.5^m$

* For the FAVOR and TORTORA cameras, the detection threshold corresponds to the detection of a transient at a 3σ level in a single frame and may be different from the real detection threshold of the difference technique being used.

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