Global MASTER-Net Highlights

Vladimir Lipunov[a,*]

[a] *Lomonosov Moscow State University, SAI, Physics Department,Moscow, Russia*

E-mail: lipunov@sai.msu.ru, lipunov2007@gmail.com

This article presents some of the results of the MASTER Global Robotic Network over the past few years. But it begins with a theoretical substantiation of the main goal of our research – the study of extreme phenomena of the Universe. We are talking about processes that, in terms of their power, approach the power of the Big Bang and go into the modern era. Our optical observations are always part of multi-wavelength international research. We are talking about the first registration of Orphan optical flare at the growth stage (AT2021lfa), the study of the brightest gamma-ray burst in the entire history of their study, extreme GRB 221009A, the multiwavelength study of the flat spectrum radio-quasar NVSS J141922-083830 covering four flaring episodes, the installation of a new MASTER-OAGH telescope in Mexico and its first highlights. We talk about the Three-stage Collapse of the Long Gamma-Ray Burst from GRB 160625B model and huge FRB monitoring by Global MASTER-Net during the COVID-19 pandemic , about probing into emission mechanisms of GRB 190530A using time-resolved spectra and polarization data, about exploring the early afterglow of GRB 190829A. In conclusion, we discuss our proposed optical candidate for a high-energy neutrino source. We have discovered the effect of a rapid decrease in the brightness of the blazar PKS 0735+17 at the time of the unique multiple detection of the high-energy neutrino IceCube-211208A.

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1. Introduction

I dedicated this invited report to my colleague, comrade and principal co-author of the MASTER Global Network Viktor Geraldovich Kornilov, who left us May 1, 2021

Figure 1. Victor Geraldovich Kornilov. The head of new photometrical methods laboratory in Lomonosov Moscow State University, SAI. The key member of MASTER team and the real professor of MSU

Immediately after the discovery of his equations, Einstein solved, at first glance, the applied problem of the radiation of gravitational waves by a system of two material points of arbitrary mass. It turns out that such a system, even without the intervention of external and internal forces, cannot be eternal. It constantly emits gravitational waves.

But there was another important consequence. The final formula for the power of GW radiation included an amazing normalization value, which Einstein called the natural power (luminosity) a combination of two fundamental constants - the speed of light and the constant of gravity: $L_E = c^5/G = 6 *10^{59}$ erg/sec. The mere fact that Einstein gave a name to this quantity speaks of its significance for science, which he foresaw. Look, what kind of universe do we live in? In the last century, it seemed that we discovered all its most powerful processes: supernova explosions, galaxies, quasars, blazars... Are these universal catastrophes so powerful? Are they really the dinosaurs of our huge zoo? How to strictly scientifically evaluate their significance for the Universe?

When Einstein was deriving his formula, he was investigating the issue of weak effects of general relativity, as physicists say, in a linear approximation. Let's try to find a powerful process in which the maximum energy is released. Let, we have a body of mass m. Let's turn it into photons in the shortest possible time. The maximum energy that can be fished out will be mc^2. And the minimum time for which this can be done is equal to the minimum size divided by the maximum speed - the speed of light. The minimum body size is equal to the gravitational radius of the black hole $R_g = 2Gm/c^2$. Then the maximum generated power in such a machine will be equal to $L_{max} \sim c^5/G = L_E$. Of course, this value will depend on the relative speed, and if a particle of mass m in the accelerator flies at us almost at the speed of light, then the light energy will be much greater than the rest energy. We are astrophysicists, we look at the Universe and find macro-objects in it: stars, galaxies, quasars. While the Universe expands, not contracts, and therefore all the Universal cataclysms only run away from us and seem weaker from that! So, now we can build the Richter scale for the Universe. Stop. But we took the formulas from the theory of gravity. But there is also quantum mechanics, which has Planck's constant. What do we take the Planck units:

$$m_P = \sqrt{\frac{\hbar c}{G}} \qquad t_P = \frac{l_P}{c} = \sqrt{\frac{\hbar G}{c^5}}$$

We divide the Planck energy by the Planck time $m_P c^2/t_P$ and again we get $L_P = c^5/G$. The Planck power L_P turned out to be equal to the Einstein luminosity L_E [1]. The Planck's Constant has dropped! Natural luminosity comes out and really fits the role of a "standard candle" for the Universe. But what can be measured with such a candle? Yes, the Universe was born with such power. However, it was 13.7 billion years ago. What now?

Figure 2 shows the vertical ratio of the luminosity of the brightest objects in the Universe to the maximum luminosity in a logarithmic (!) scale. It turns out that the brightest objects in the universe are hundreds of billions of times weaker than what can be in nature? In the figure, horizontally - the characteristic lifetime of an object or phenomenon. The left ordinate axis is in erg/s and means the powerfull of the objects, that are listed in caption (Fast Radio Bursts, Soft Gamma Repeaters, Gravitational Wave from BH(NS) merging, Short Gamma Ray Bursts, Long Gamma Ray Bursts, Kilonova, Super Novae, Blazars, Super Liminal Super Novae); the right ordinate axis is the diameter of the telescopes for these objects discovery and investigation; the upper axis of abscissa is the duration of these events. Pay attention: to the chain of objects from right to left: galaxies, quasars and blazars. The greater their power, the shorter the time of their activity. For example, galaxies themselves do not change their luminosity for billions of years. Quasars, which are a hundred times more powerful, live a hundred times shorter, and the phenomenon of a blazar flare, during which it becomes hundreds and thousands of times brighter than quasars, lasts only a few months. But can not there be even more powerful phenomena in our Universe, for shorter periods of time? And do we have objects whose power reaches or approaches the maximum limit of c^5/G?

It turns out that the processes of collisions of relativistic stars - neutron stars and black holes - are really going on in the Universe. These densest objects in the universe collide in the shortest possible time and are able to radiate a decent part of their rest energy in a fraction of a second.

For two neutron stars, the after phase lasts a couple of milliseconds, and black holes are an order of magnitude or two larger and, accordingly, emit gravitational waves at frequencies of hundreds of hertz.

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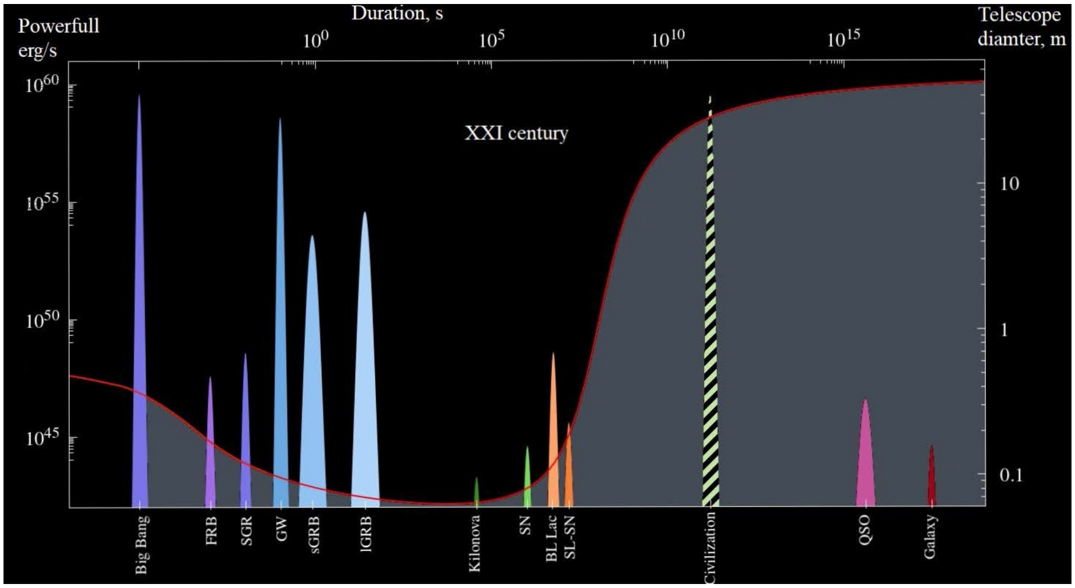

Figure. 2 The Universe in XXI centure in 5^{th} dimension. From left to right: Fast Radio Bursts, Soft Gamma Repeaters, Gravitational Wave from BH(NS) merging, Short Gamma Ray Bursts, Long Gamma Ray Bursts, Kilonova, Super Novae, Blazars, Super Liminal Super Novae

What kind of macroscopic reactions take place in the Universe and what is their cross section or, in simple terms, how often do they happen in the Universe?

In the early 80s of the last century, we came up with a special computer code "Scenario Machine" (by Kornilov & Lipunov in 1983 [2] and Figure 3 with main principal moments of the Scenario Engine). I want to say right away that we still do not know for sure the exact laws of the evolution of these objects in the Universe, like, for example, Newton's equation of motion. And there is only a scenario of their birth and life, and sometimes transformation into something new. But why Machine? Yes, because we did not just try to build a Extreme Universe, but to calculate a whole set of relativistic Universes for different scenarios of evolution and then, compared with what was already discovered by astrophysicists in the sky. And after this comparison, choose the most likely of all reasonable and possible scenarios.

We understood that the most interesting thing in the life of relativistic stars happens when they live together. Moreover, a good half of all the stars in the universe are binary.

In the computer, we filled in all the more or less realistic laws of stellar evolution, the parameters of which made it possible to test different scenarios. The engine of this machine was a two-stroke diesel engine with two blocks of laws of evolution of normal stars and relativistic stars. The initial distributions over masses, orbits, rotational velocities and magnetic characteristics (for relativistic stars) served as gasoline, which were scattered by a random number generator in accordance with the observed characteristics of newborn stars (Monte Carlo method).

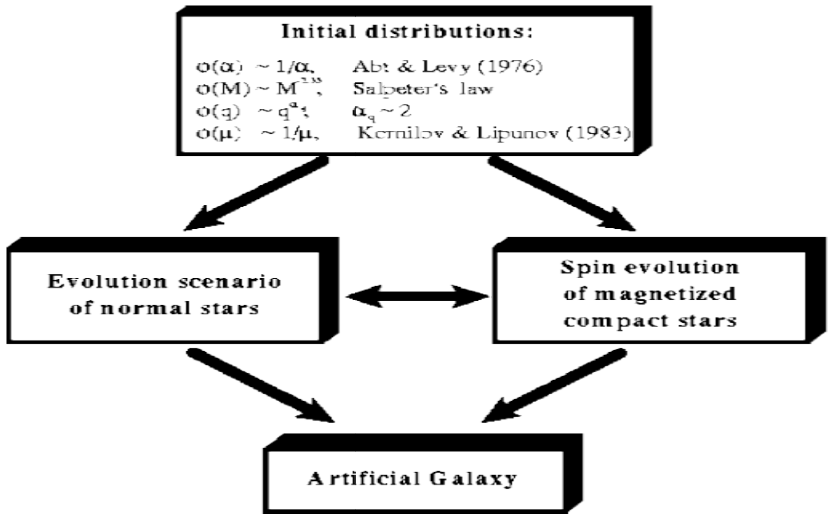

Figure 3. The block diagram of the Scenario Engine looked quite simple.

Thus, we modeled tens of thousands of stellar tracks in a multidimensional space of parameters of orbits, masses, rotations around an axis, and magnetic fields for two components of each system. Especially for programmers, I will emphasize that in 1982, when we started this project, we had at our disposal a BESM-4 machine with 4 kilobytes of RAM! At the exhaust, our magical machine generated not harmful carbon monoxide gases, but myriads of relativistic objects never before seen by mankind. There were three reactions of different types and with different products at the end.

NS + NS -> GWB + GRB + BH (NS) + KN ~1/10 000 years (*Lipunov et al. in 1987[3]*)

Two neutron stars (NS) are able not only to give rise to powerful gravitational wave (GWB) and gamma-ray (GRB) pulses, but also to give classical astronomers a completely new astronomical phenomenon - the kilonova (KN). In addition, after the merger of neutron stars, an object remains - either a light black hole (BH) or a heavy neutron star. Everything depends on the properties of nuclear matter. The kilonova optical flare accompanying the merger of neutron stars was predicted by Blinnikov et al.in 1984 [4] and was later named Kilonova by Bogdan Pachinsky in 1998 [5].

Gamma-ray burst in 999 cases out of 1000 will miss the Earth. But Kilonova, although it is millions of times weaker than a gamma-ray burst, is omnidirectional and will not fly past us. In addition, it is 1000 times more powerful than the nova flare, and can be observed with small telescopes (up to 1 meter) at distances of hundreds of megaparseparsecs. The mixed reaction is also prolific, but calculating its probability is much more complicated and took 10 years to develop the Script Machine [6]:

NS + BH -> GWB + BH+GRB +KN ~1/100 000 years

It differs little from the previous one in terms of products on the right side and still generates the Kilonova phenomenon.

And finally, the third type of reaction is the merger of black holes:

BH + BH -> GWB + BH ~1/200 000 years (by Lipunov et al. in 1997a,b,c [7-9])

Here, almost all of the released energy is carried away by gravitational waves. And electromagnetic radiation in the standard scenario is unlikely and should not have been expected in the first decade of operation of gravitational wave detectors. Thus, for the first time we managed to predict not only the result of the first successful registration of gravitational waves, but also to determine the distance to the first registration of Kilonova!

Of course, we first calculated the probability of a collision of neutron stars in a galaxy like ours in 1987. The probabilities of a mixed-pair merger reaction for 1995 and binary black holes in 1997.

In addition to these processes, the Scenario Machine made it possible to calculate other processes in our Extreme Universe. It was about the formation of rapidly rotating black holes, which are accompanied by long gamma-ray bursts. In addition, another new phenomenon in the Universe, Fast Radio Flares, was also predicted (Lipunov & Panchenko in 1996 [10]). All the main processes of the Extreme Universe were modeled, and by the end of the 20th century, the task of experimental research in different electromagnetic ranges arose [1-92].

2. MASTER Global Network.

After the outstanding discovery of the intrinsic optical emission of 8th magnitude gamma-ray bursts (Akerloff et al. in 1999 [11]), it became clear that extreme processes can be observed with the smallest but robotic telescopes. Since 2002, the MASTER team (Lipunov, 2003 [12]) has joined the search for superpowerful phenomena in the Universe, which has discovered more than 3500 optical flares in the Universe to date [12-20, 22-27]. Among the most significant discoveries there were the discovery of the polarization of the intrinsic optical emission of gamma-ray bursts (Troja et al. in 2017 [13]) and the independent discovery of the kilonova GW170817 (Lipunov et al. in 2017 [14-17]) .

It should be emphasized that the distance to the first recorded neutron star collision by the LIGO/Virgo system [15] coincided with the prediction of the Scenario Engine with amazing accuracy. This leaves no doubt about the correct interpretation of the event as a result of the evolution of a massive binary system that was born about 10 billion years ago (by Lipunov et al. in 2018 [16]). Indeed, in one of the highest quality calculations of the frequency of mergers in the region limited by the catalog of galaxies to 50 Mpc, it turned out to be ~3 yr^{-1} ([6], Figure 4). The active operating time of LIGO/Virgo during the O2 period was 1/3 of a year. Therefore, the ratio of the distance predicted by the Scenario Machine to the observed distance is d_{SM}/d_{obs} = (4/5) 1/3 = 1.08.

Next, we will talk about the most significant discoveries of the MASTER Global Network over the past few years since the last conference.

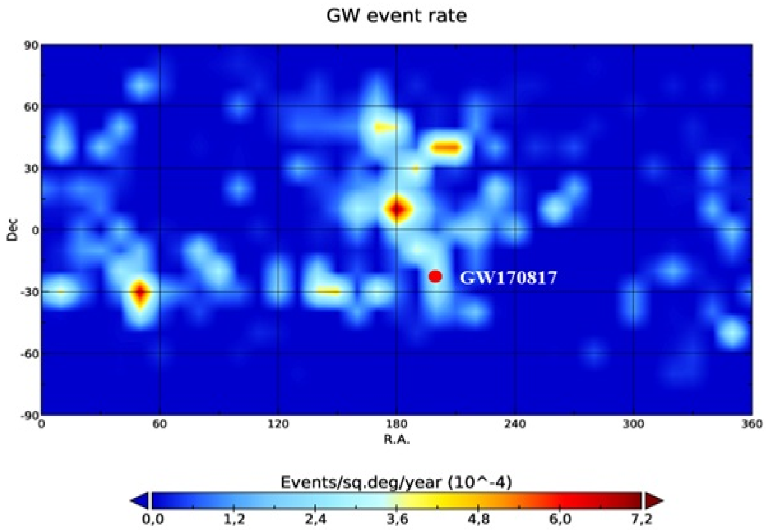

Figure 4. Gravitational wave sky. The color of the spots from blue to red is proportional to the probability of receiving a signal from merging neutron stars. The integral probability over the entire sky is 3 events per year inside 50 Mpc [16,18].

3. Orphan optical flare as Smooth Optical Self-similar (SOSS) emission afterglow, localization in time

We managed to detect an "orphan" at the stage of growth, that is, a young orphan: apparently this is a new subclass of objects that can be called the "Homeless of the Universe". The MASTER-OAFA robotic telescope located in Argentina [19] was able to detect a new type of object - the growing orphans of the Universe [20].

Once, at the beginning of the 2000s, our robotic telescope MASTER I stood in the village of Vostryakovo, Domodedovo district. In essence, this is a former village 2 kilometers from the Airport where our friend and co-author Alexander Krylov lived. It was a gray, penniless time and the most unpromising for an experiment, especially one that would not be inferior to the leading developments of Western scientists. But, by that time, Alexander Krylov had built the building of an amateur observatory. And a relatively wealthy businessman appeared on our life path - Sergey Mikhailovich Bodrov, who bought us the world's largest camera and financed the creation of Russia's first real robot-telescope. And I managed to captivate Viktor Kornilov - my classmate, comrade and real experimenter of our astronomy. It was a time when there were practically no professional digital cameras in Russia - these astronomical eyes of the 21st century, and I love such tasks when everything and everyone seems to be against it. Often standing at the window, looking at the bleak landscape of the devastation of the 90s, we dreamed of how to make such a discovery that any world-class magazines snatched from us with our hands. I even formulated the most important observational problems unsolved by mankind, without which it is impossible to build a correct picture of the Extreme Universe. I was sure that gamma-ray bursts - the most powerful electromagnetic explosions - a phenomenon that occurs at the time of birth rapidly spinning black holes at the other end of the universe. Two tasks lay on the surface: this was the discovery of the polarization of its own (that is, synchronous with gamma) optical radiation, and the second was an attempt to see the formation of a black hole right away in visible light - without any gamma radiation. Of course, it must be a magical telescope - it must think, know and be able to read the starry sky.

So in the fall of 2002, this story began near Moscow. We solved the first problem 14 years later with the help of the Canarian robot MASTER-IAC (a joint Russian-Spanish project). The world saw for the first time that the mouth of the most powerful gun in the universe was formed by a magnetic field generated during the collapse of a dying mother star. But the second task turned out to be technically much more difficult and resembled a Russian fairy tale: go there - I don't know where and bring it - I don't know what. Well, more precisely - after 15 years we already knew approximately what we were looking for. We ourselves have deciphered the cry of the star's last hope for help, which is forever leaving our Universe. The fact is that over the past 20 years, the MSU MASTER Global Network has become the world leader in early and synchronous observations of gamma-ray bursts and has discovered a special formula that describes the message cipher. We called this light burst-message SOSS-emission, which obeys the laws of propagation of a relativistic point explosion. That's what we were looking for and found ... in May last year. And we not only competed with the American hundred million dollar robotic telescope (project of Zwicky, Caltech [21]), but even managed to be the first to photograph the "orphan " .

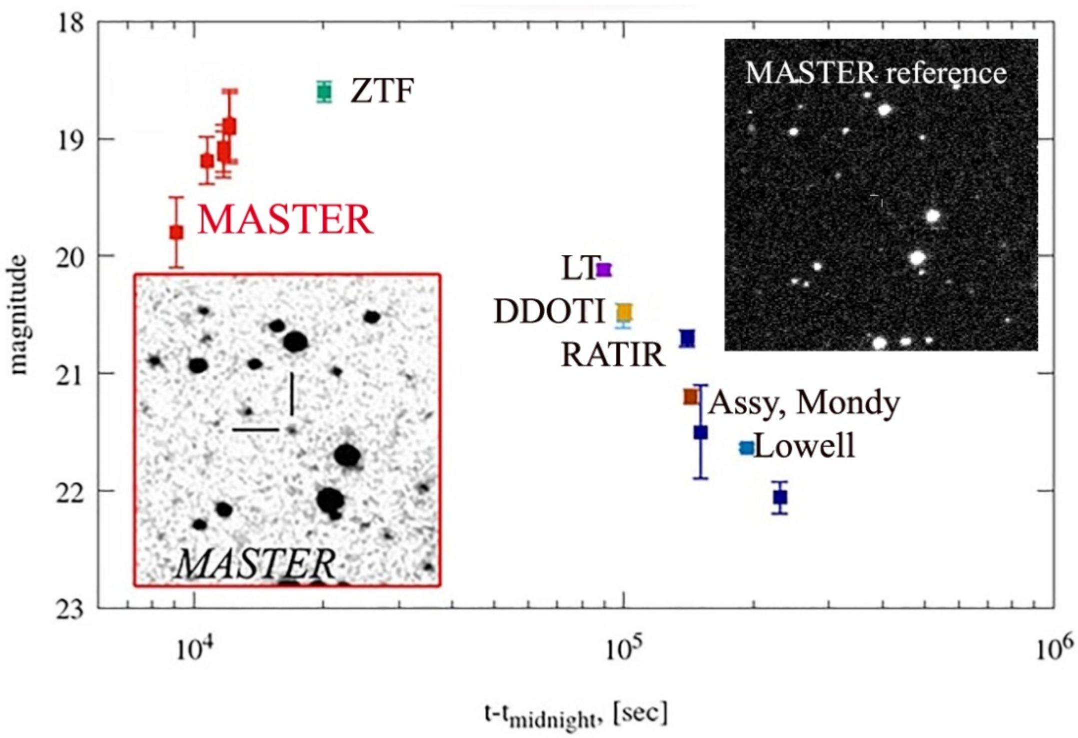

Figure 5. The image and light curve of AT2021lfa/ZTF21aayokph. The red points are MASTER-OAFA (Argentina), the green one are ZTF discovery data [20].

On May 4, 2021 at 05:34:48 UTC, the ZTF project detected an unusual optical transient AT2021lfa/ZTF21aayokph with a red filter brightness of r = 18.6. At the same time, it was found that there is no object in the images taken 2 days earlier. Subsequent observations with other instruments showed a further decrease in brightness, and a host galaxy with a redshift of z = 1.063 and an X-ray transient with a typical flux for X-ray afterglows of gamma-ray bursts [21] However, MASTER-OAFA imaged this object three hours early during own inspection survey !

As the light curve (Figure 5) shows, the brightness of the optical transient in the MASTER-OAFA images steadily increases from the first images, remaining below the ZTF value in their first frame. The validity of this statement is at the level of 7σ. Therefore, we conclude that the peak brightness was between the last MASTER frame and the first ZTF frame.

This non-monotonic, smooth light curve shape indicates that AT2021lfa is an example of GRBs with smooth optical self-similar emission (here, SOSS-like GRBs [81]) first identified by the MASTER team in 2017. SOSS GRB afterglows are described by a universal model that allows one to determine both the time of the burst and the time of the peak from the shape of the light curve. The model may indicate the synchrotron nature of the radiation generated by an ultrarelativistic shock wave in compressed interstellar gas or in the stellar wind of an ancestor star. The decaying portion of the light curve is determined by the cooling time of relativistic electrons and the power-law decrease in the density of the medium. Such SOSS emission is practically unrelated to its own optical radiation, which most likely occurs in the backward shock wave inside the jet and is usually visible simultaneously with gamma radiation.

The connection with gamma-ray bursts becomes even more obvious when using X-ray data from the Swift observatory [92,93]. The flux in the 0.3-10 keV flux was $2.3 \cdot 10^{-13}$ erg/cm^2/s 1 day after ZTF detection, which corresponds to a luminosity of $1.9 \cdot 10^{45}$ erg/s at z=1.0632. Using this estimate, we can calculate the instantaneous gamma-ray flux density of the transient if it were a gamma-ray burst. Assuming that the Swift-XRT observations were made about a day after the flare, we obtain the following value $E_{\gamma,iso} > 10^{51}$ erg. Comparison of the X-ray spectrum of AT2021lfa is consistent with the expected values according to the standard afterglow theory. Thus, it can be assumed that the observed X-ray transient resembles a gamma-ray burst in the late stages of the afterglow.

To eliminate the possibility that this transient is a typical long gamma-ray burst, which for some reason was not automatically detected by gamma-ray telescopes, a search was made in the Fermi/GBM burst catalog, the list of subthreshold triggers, the Swift GRB archive, and the GCN archive . No gamma-ray bursts were detected near the location of AT2021lfa during the found time period. However, none of the space observatories detected a gamma-ray burst in the region of the moment of the beginning of the explosion that we found. From the point of view of observations, this phenomenon is Orphan GRB.

Thus, experimentally and theoretically, we have shown that the optical transient AT2021lfa is an orphan burst with an X-ray afterglow similar to gamma-ray bursts, without the presence of the gamma-ray burst itself. This phenomenon can be explained in terms of the so-called dirty fireball model with a low Lorentz factor and an underdeveloped jet. Moreover, using the SOSS emission model, it was possible to find the moment of the explosion. We emphasize that the smooth nonmonotonic nature of the optical SOS emission of gamma-ray bursts, discovered for the first time in this study, demonstrates the self-similar nature of the explosion and the transition of the relativistic shock wave to decay. This smooth behavior can be distorted in other cases by time inhomogeneities of the prolonged jet generation process.

4. The new observatory MASTER-OAGH in Mexico.

In December 2021, in just less than 10 days, we installed the MASTER-OAGH robotic telescope at the Guillermo Aro Observatory (Mexico) , the 9th MASTER telescope (Figure 6 with first light Rosetta Nebula, Figure 7 with last map with MASTER telescopes location and Figure 8 with first optical transient (OT) outburst detected by MASTER-OAGH auto-detection system). On one of these ridges there is an observatory to them. Guilherme Aro. There are two humps on the ridge: on one is a 2-meter telescope (workshops, canteen, instrument room, observation room). On the other one there is a MASTER telescope now. The first light was Rosette nebula (Figure 6) in BVRI filters (Johnson/Bessel, [22,23]).

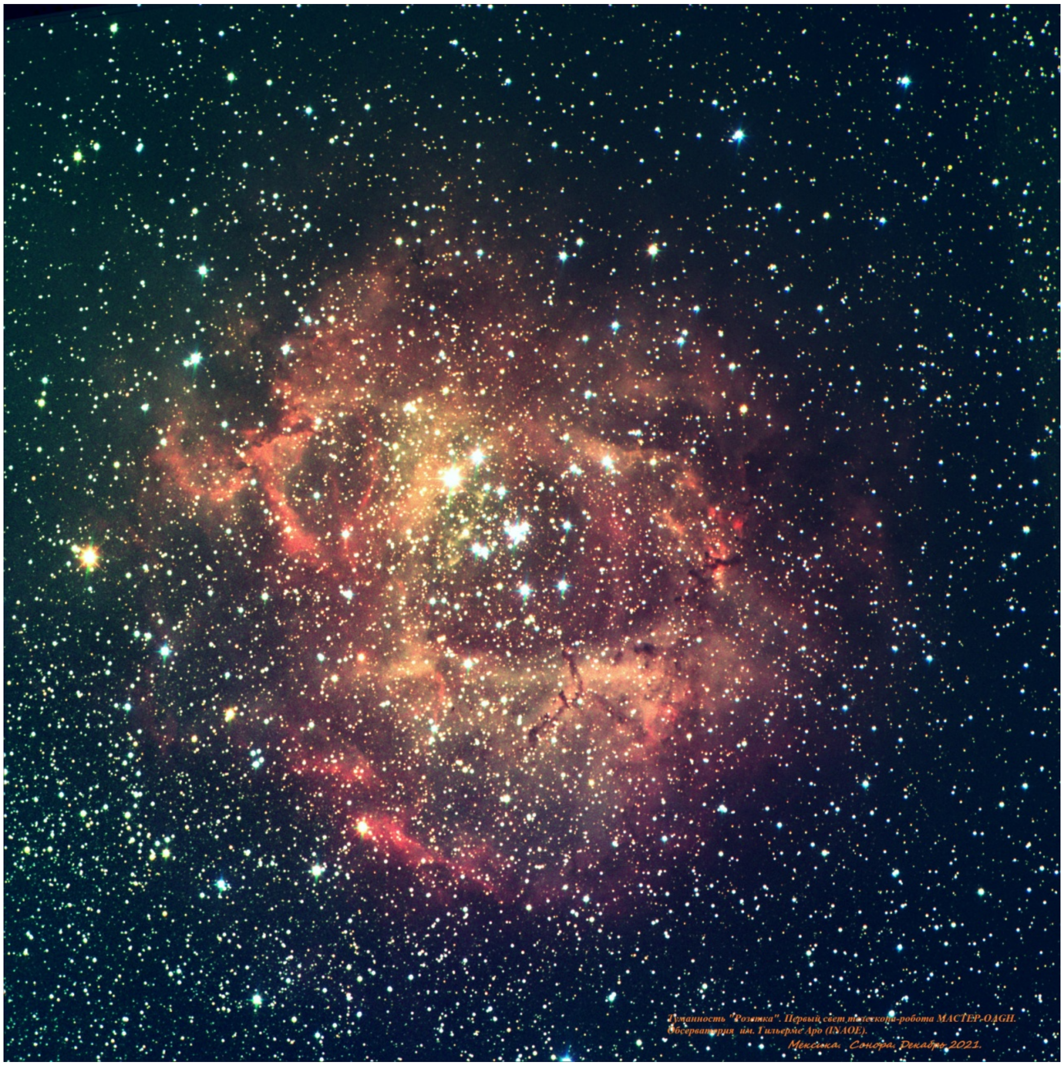

Figure 6. Rosette nebula image by MASTER-OAGH. The first light in Guilermo Haro observatory, Cananea, Sonora, Mexico. December 2021.

Every MASTER observatory has identical scientific equipment, including twin telescopes (2 x 4square degrees), own designed photometers [23] with BVRI and PP filters, the same CCD (for simultaneous observations of the target and possibility to observe in opened mode (8 square degrees)), quick mount (several dozens degrees per second for quick pointing to new, unknown befor alerts coordinates of high energy astrophysics events, registered by space gamma-observatories or gravitational wave observatories, or neutrino observatories and other). Fully robotization MASTER software automatically controlled weather conditions, Sun and Moon ephemeries (full Moon is important for wide field optical systems that is taken into account to automatic MASTER planner of alert, inspection and regular survey observations).

And the main MASTER-OAGH feature is auto-detection system, with online reduction and new optical transients detection.

Figure 7. MASTER Global Robotic-Telescopes Network location since December 2021.

The first optical transient (OT), detected by MASTER-OAGH real-time auto-detection system was ***MASTER OT J153539.77-461415.4*** (Figure 8, ATel 15180 [25]).

It was found during MASTER inspection of Fermi trigger 664738369 ($T_{trigger}$ =2022-01-24 17:32:44.36 UT, R_{stat}=5.08deg.) inspection at R.A., Dec.(2000) = 15h 35m 39.77s -46d 14m 15.4s at 2022-01-25.50915 UT with unfiltered [22,23] $m_{OT} = 14.4^m$ and image limiting magnitude $m_{lim}=17.6^m$. The second image was at 2022-01-25.54848UT with the same brightness. Taking into account this Fermi alert trigger time, this optical transient should not be connected with this GRB optical counterpart.

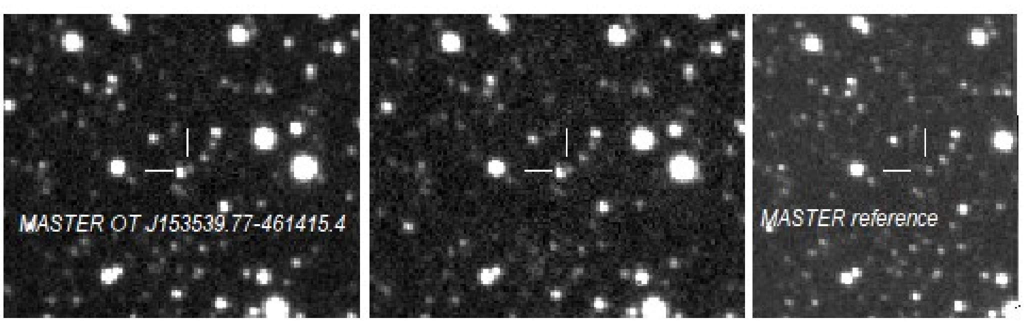

Figure 8. MASTER OT J153539.77-461415.4 images and reference one at right one [25].

This OT was seen in 3 images (also checked for minor planets and orbital artefacts at this place). The reference images in MASTER archive were used at 2018-09-12.91464 UT with unfiltered $m_{lim}=17.8^m$, at 2021-02-03 23:14:29UT with unfiltered $m_{lim}=17.6^m$, at 2016-07-09

18:19:42UT with mlim=19^m. There was no OT sources in AAVSO database at discovery time, in VIZIER there was no Gaia/USNO sources inside 3" , that gives 22m limit in object history and >5.6^m of current outburst amplitude (0.2B+0.8R by USNO-B), there was only VISTA source in 0.7", so the classification of optical transient was the outburst of dwarf nova with amplitude more than 5.6^m.

5. A structured jet explains the extreme GRB 221009A

On October 9, 2022, an event occurred that should not be repeated for the next thousand years! This is the brightest gamma-ray burst ever observed by gamma-ray telescopes. In other words, the GRB 221009A explosion (Figure 9) surpassed in its energy all the previous ones in 55 years of observations: in a few tens of seconds, before our “eyes”, 5 solar masses turned into photons. But that's only half the story. The gamma-ray burst was not only the most powerful, but became the closest of all observed gamma-ray bursts to which it was possible to determine the distance.

The probability of this event is 1 time in 1000 years! But this is a real problem that can shake the very foundations of our ideas about what happens to a star when it tries to make holes in our Universe!? After all, the cause of gamma-ray bursts is considered to be the collapse of a rapidly rotating massive star into a black hole.

In the work O’Connor et al., 2023 [26] of multiwave observations of the most powerful and at the same time one of the closest gamma-ray bursts in the entire 50-year history of their observations. Such a combination of power and proximity of the explosion should happen once every 1000 years, which seems incredible and should change our understanding of the nature of the eruption of energy, which in the standard picture turns out to be equivalent to the rest energy of 5 solar masses of matter. Analysis of X-ray, optical, high-energy gamma afterglows leads to a revision of the standard ideas about the structure of relativistic jets generated by a black hole that is formed before our eyes. The result of the work was a model of a “structured jet”, in which at different times (at different depths), at different wavelengths, radiation goes inside different cones. This makes it possible to reduce the estimate of the real explosion energy to standard values and make the probability of such events quite acceptable: once every several decades.

Multiwave observations were carried out in automatic mode on space telescopes (Enrique Fermi Space Observatory, Neil Gerchel Observatory Swift/XRT, NuSTAR,XMM-Newton, Konus-Wind) and ground-based optical facilities (MASTER Global Network, COATLI telescope and HUITZI imager at the Observatorio Astronomico Nacional on the Sierra de San Pedro Martir, Figure 9) . This made it possible to compare the evolution of the afterglow of a gamma-ray burst in the widest range from radio to gamma-ray photons with energies of 18 TeV. The “knee” effect (“jet brake” in English literature) is the following: the afterglow falls off gently at first, and after a while it goes steeper. In logarithmic coordinates (Figure 9), the light curve becomes like a bent leg. The appearance of the knee is explained as follows. Particles flying at ultrarelative speeds emit light primarily forward in a narrow cone (the "spotlight" effect), which is wider the slower the particle speed. The relativistic jet also resembles a cone, but with a different, wider opening angle. While the movement is fast, the observer does not see the edge of the jet and it seems to him that the explosion resembles a ball, but at some point the particles losing energy slow down so much that the radiation cone becomes larger than the jet cone. And now the observer sees the edge of the jet, which almost does not shine.

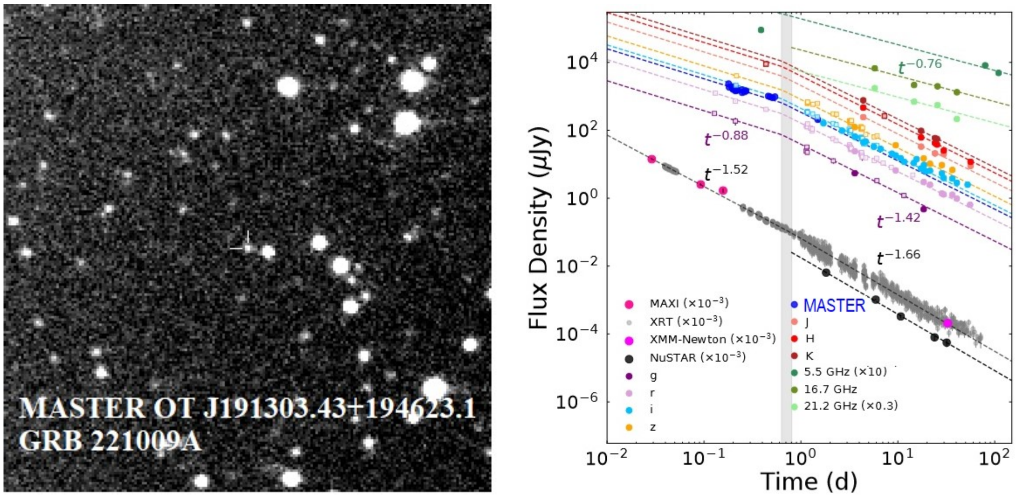

Figure 9. GRB 221009A optical counterpart by MASTER (left) and light curves of the afterglow of the explosion in different beams: from γ emission to infrared one [26].

The MASTER contribution was the following: MASTER-SAAO telescopes located in South Africa and MASTER-OAFA in Argentina were the first who reported the unusual behavior of the optical afterglow, which even after three hours retained its brightness. As a result, the history of the changes in the afterglow on the first night was obtained (blue circles on the light curve up to the “knee” in Figure 9). The participation of the MASTER Global Network in the most advanced multi-channel studies of fast phenomena in the Universe shows that robotic distributed networks, sometimes inferior to large optical telescopes in size, still receive unique data that can explain their most paradoxical properties.

6. Three-stage Collapse of the Long Gamma-Ray Burst from GRB 160625B Prompt Multiwavelength Observations .

As a result of our analysis of synchronous multiwavelength observations, we propose a three-stage collapse scenario for this long and bright GRB. We suggest that quasiperiodic fluctuations during prompt stage may be associated with forced precession of a self-gravitating rapidly rotating superdense body (spinar [27], Figure 10), whose evolution is determined by a powerful magnetic field. The spinar's mass allows it to collapse into a black hole at the end of evolution.

Sir Arthur Eddington did not like black holes, although he himself was the first to welcome Einstein's theory of relativity (special and general). One of the greatest astrophysicists of the 20th century, a scientist who discovered the secret of the glow of stars and realized before anyone else that the stars are not eternal, liked to repeat that the Lord God, who created the world, would not allow matter to leave our Universe forever. Apparently, Eddington was wrong: black holes are most likely to form. But in any mistake of a great scientist there is also an element of truth. Yes, we now know that a star of "dangerously large" mass must go forever below the event horizon. But in the process of their evolution, the stars, by all means, are trying to lose "extra weight" so as not to become a black hole. This desire to "spread out" can be called "Eddington's syndrome." So all blue stars constantly puff out their cheeks and blow out millions of billions of tons of matter per second in the form of a stellar wind, and in binary systems they often cunningly try to “borrow” the extra mass to their neighbour! The only force that can resist the force of gravity is the centrifugal force. A star that spins too fast can't just turn into a black hole. That is why in nature there cannot be black holes with a moment of rotation greater than a certain one. So, an object in which the gravitational force is balanced by the centrifugal force is called Spinar 1. Obviously the spinar will live as long as it keeps its torque. In other words, Spinar will collapse as fast as dissipative forces take away its angular momentum. The spinar is amazing and behaves quite differently from the spinning top, which, by losing momentum, slows down the speed of rotation. The spinar, on the contrary, accelerates, like a figure skater who reduces with the rotation of her arm. By the way, the figure skater does work, and in the process of spinar compression, the work is done by gravity.

Thus, the work is devoted to the interpretation of synchronous multiwavelength observations of the gamma-ray burst GRB 160625B by Russian space and ground systems [13, 27] On June 25, 2016, one of the brightest flares in the history of GRB observations - GRB 160625B, occurred. The most detailed optical observations were made by the Global Network of Robotic Telescopes of Moscow State University MASTER. One of the three brightest flares in the history of observations attracted the attention of almost all ground and space observatories in the world. The most detailed and diverse optical observations in the optical range were made by the MASTER network telescopes located in the Crimea and the Canary Islands. Firstly, special Wide-Field Optical Cameras (MASTER-SHOCK) shot a "movie" with a large temporal resolution and almost without pauses. Secondly, the main robotic telescopes of the MASTER network carried out synchronous recording with gamma and optical radiation. Thirdly, one of the MASTER telescopes recorded the polarization of synchronous optical radiation for the first time [13]. Our achievement was devoted mainly to the external manifestations of one of the three historical explosions recorded by mankind - the formation of relativistic emissions. However, we were constantly worried that not all domestic results were included in that article and, most importantly, what we wanted to find out: what, in fact, happened there - at a distance of almost 10 billion light years from Earth? Now almost no one doubts that "long" (more than 4 seconds long) γ-ray bursts are generated in the process of formation of rapidly rotating black holes. However, almost no one can say how the "central machine" of this event works. And here are the amazing three features of this event, registered by gamma and optical telescopes, were explained within the framework of Spinar's paradigm, which is completely not accepted in the West.

Observations of a gamma-ray event recorded by the Fermi Space Observatory on June 25, 2016 are shown in black (G1 - precursor, G2 - main pulse, G3 - secondary pulse was best seen by the Lomonosov BDRG gamma detectors, see Figure 10). Blue color shows the flux of hard radiation obtained from the space experiment "Konus-Wind" by our colleagues from the Institute. Ioffe (St. Petersburg). Brown color shows data from the Lomonosov observatory. Red shows optical observations of ground-based counterparts of the SHOK cameras in the Canary Islands. Blue stars are data from the Crimean robotic telescope MASTER-Tavrida.

As you can see, the long burst turned out to be quite long and 3 events can be distinguished: G1 - a precursor, G2 - the main pulse, G3 - the repeated pulse was best seen by the Lomonosov BDRG gamma detectors. In addition, the analysis of optical radiation showed a non-random quasi-periodicity. It seems that starting from the 50th second of the main pulse G2, some quasi-static rotating object that lives up to 450 seconds and then gives the last burst of gamma radiation G3.

To explain these three flares we use Spinar's model. The Spinar model of stellar mass - namely, the collapse of stars after they run out of nuclear fuel - was proposed by Lipunov in 1987 [28] So what is happening (see the diagram on the left: From top to bottom. Gray color shows a star that has run out of nuclear fuel and a massive rotating magnetized core (black circle) begins to freely fall (collapse) to the center. However, at some point, the core spins up and the centrifugal force balances the gravitational one and the fall stops - a spinar is formed.In the performance of Kamilla Valeeva, this transition is called the “Bedouin jump”. In this case, half of the gravitational energy is converted into the energy of Spinar's rotation, and the second is emitted as a precursor of a gamma-ray burst (event G1). Further, the spinar quickly or slowly (depending on the magnitude of its magnetic moment) loses the moment of rotation. Then, shrinking, it spins like a figure skater - an accelerating rotation ("vertical camel").

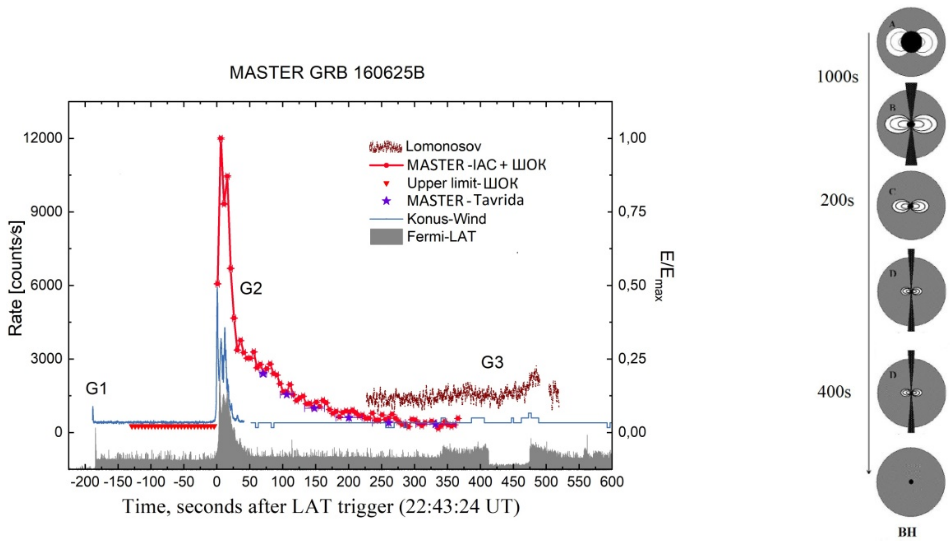

Figure 10. (**left**) The results of observations of the gamma-ray burst GRB 160625B in different energy ranges are presented. It can be seen that the G3 event was most reliably recorded by the gamma-ray detectors of the Lomonosov space observatory. (**right**) The three stage collapse.

The closer the event horizon, the faster the contraction and rotation of the nucleus, and usually everything ends with a much more powerful flash G2 - the collapse of the nucleus into an extremely rotating black hole. But in the case of GRB 160825B, it is not so simple. If we choose the mass of the nucleus close to the mass limit of a neutron star (Opeheimer-Volkov limit), then the collapse will stop - nuclear ones will come to the aid of centrifugal force. And then there will be something like a strongly quasi-static neutron star - a pulsar. If its magnetic field exceeds 310^{14} ·Gauss, then something similar to Magnetar will turn out. In our case, we got ~10^{15} Gauss (see block of collapse curves). However, this is a mixture of Spinar and Magnitar. The fact is that the mass of a neutron star slightly exceeds the Openheimer-Volkov limit, and Spinar, losing the moment of rotation, continues to shrink and finally collapses into a black hole - the G3 event. So, it became clear why the article in our article appears "three-stage collapse."

It must be understood that on the right you see a numerical calculation, although of a relativistic, but approximate model. It seems that the curve second from the top - the change in energy emitted by the Spinar per unit time - is weakly consistent with the sharp profile of the main impulse of the gamma-ray burst (G2 event). But you need to understand that you have the energy released in front of you. And the observed is the part that escaped in the relativistic jet. But the very appearance of a jet is a threshold process, and therefore the observed curve will be much sharper, especially at the beginning. The jet must break through the shell of the star, which in general during this time while the spinar collapsed did not even budge! But then it will slowly go away and in a week or two a weak supernova will flare up.

As a result of our analysis of synchronous multiwavelength observations, we propose a three-stage collapse scenario for this long and bright GRB. We suggest that quasiperiodic fluctuations during prompt stage may be associated with forced precession of a self-gravitating rapidly rotating superdense body (spinar), whose evolution is determined by a powerful magnetic field. The spinar's mass allows it to collapse into a black hole at the end of evolution.

7. A multiwavelength study of the flat spectrum radio-quasar NVSS J141922-083830 covering four flaring episodes

We took part in multiwavelength observations and a model of the flat-spectrum radio quasar NVSS J141922-083830 ([29], Figure 11), originally classified as a blazar candidate of unknown type in the Third Catalog of Active Galactic Nuclei. These observations demonstrates the effectiveness of one of the three incarnations of the MASTER: namely, the MASTER can not only be the fastest telescope capable of responding to automatic target designations of space observatories, and not only obey our will as an Internet telescope, but also itself, in its free search to discover new phenomena and objects in the sky. The article begins with a magnificent triptych of a fully formed MASTER-Kislovodsk robotic telescope.

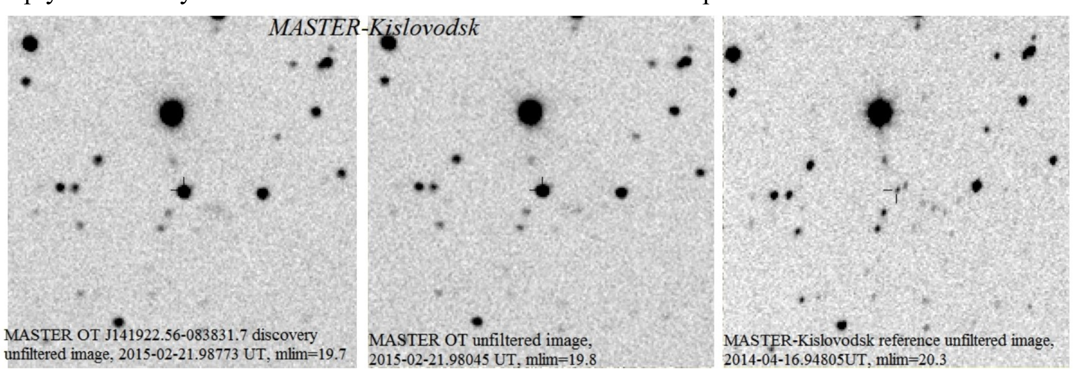

Figure 11. From left to right: two images of the quasar taken on February 21, 2015 by MASTER. The third one is reference image, taken in April 2014, almost a year before the flare was discovered. This is an example of MASTER auto-detection system work [29].

It all started with the fact that one of the telescopes of the MASTER MSU Global Network, located in the Caucasus, detected relatively bright flashes (with an amplitude of more than 3 magnitudes) were observed on February 21, 2015 and September 8, 2018. Literally a week later, one of ehe largest telescopes in the Southern Hemisphere - the 10-meter South African Large Telescope (SALT) - received an optical spectrum in which emission lines were detected with a redshift of z = 0.903, which corresponds to a distance of 10 billion light years. Analysis of data from the American gamma-ray observatory Fermi-LAT was carried out in a quiet mode (data for 5 years) and during four bright flare states in February-April 2014, October-November 2014, February-March 2015 and September 2018.

There is a hardening of the gamma-ray spectrum during the last three flare periods with a power-law spectral index Γ=2.0-2.1 [29]. The maximum level of the gamma-ray flux was observed on October 24, 2014 [29]. The multiwave spectral energy distribution during the flare in February-March 2015 confirms earlier evidence that this blazar belongs to the FSRQ class.

The ultra-wide spectrum extending over 11 orders of magnitude from optics to near-pump energies of gamma-ray photons is well explained by the lepton model with typical FSRQ parameters. However, the hadronic origin of high-energy radiation cannot be ruled out either. That is, there is still a damn question, the answer to which has required (and will still require) the cost of several billion dollars in American taxpayers, remains open: is the relativistic fountain at the other end of the universe a stream of light particles (leptons) like electron-positron pairs, or a black hole, unable to eat more, spews streams of heavy nucleons, polluting intergalactic space. However, the astronomical problem of object classification is solved.

Figure 12. Telescope-robot MASTER-Kislovodsk.

8. Huge FRB monitoring by Global MASTER-Net.

The phenomenon of fast millisecond radio bursts (FRBs) was actually predicted by MSU astrophysicists Ivan Panchenko and Vladimir Lipunov 10 years before their discovery in 1996 [30]. Such one-time radio bursts, accompanied by the death of an object, could be a harbinger of the merger of two neutron stars or a neutron star and a black hole, was suggested in [31] with MASTER observations.

In 2007, Australian radio astronomers analyzing archival observations from the Parkes radio telescope [95] encountered ultrafast flares for the first time. About a hundred such sources have now been discovered. Of course, the authors of the prediction of a new phenomenon in the Universe would like to understand whether these are the sources that they dreamed about 25 years ago. At the beginning of 2020, the situation with radio bursts was reminiscent of the first 20 years of research on gamma-ray bursts: radio bursts came from an empty place and were only visible in one range.

When the COVID-19 pandemic began, and all conventional telescopes, except for robots, got up, we tried to catch the firebird of modern astrophysics in our network. Of course, it is easier to find a needle in a haystack than not to sleep through for many weeks the moment when for one thousandth of a second a distant flash ignites at a distance of a billion light-years. Every night we sent out one of the brothers - robots MASTER. One (MASTER-Tunka on Baikal) managed to catch a fairy-tale creature by the tail - but only feathers remained in his hands (scientifically, the upper limit).

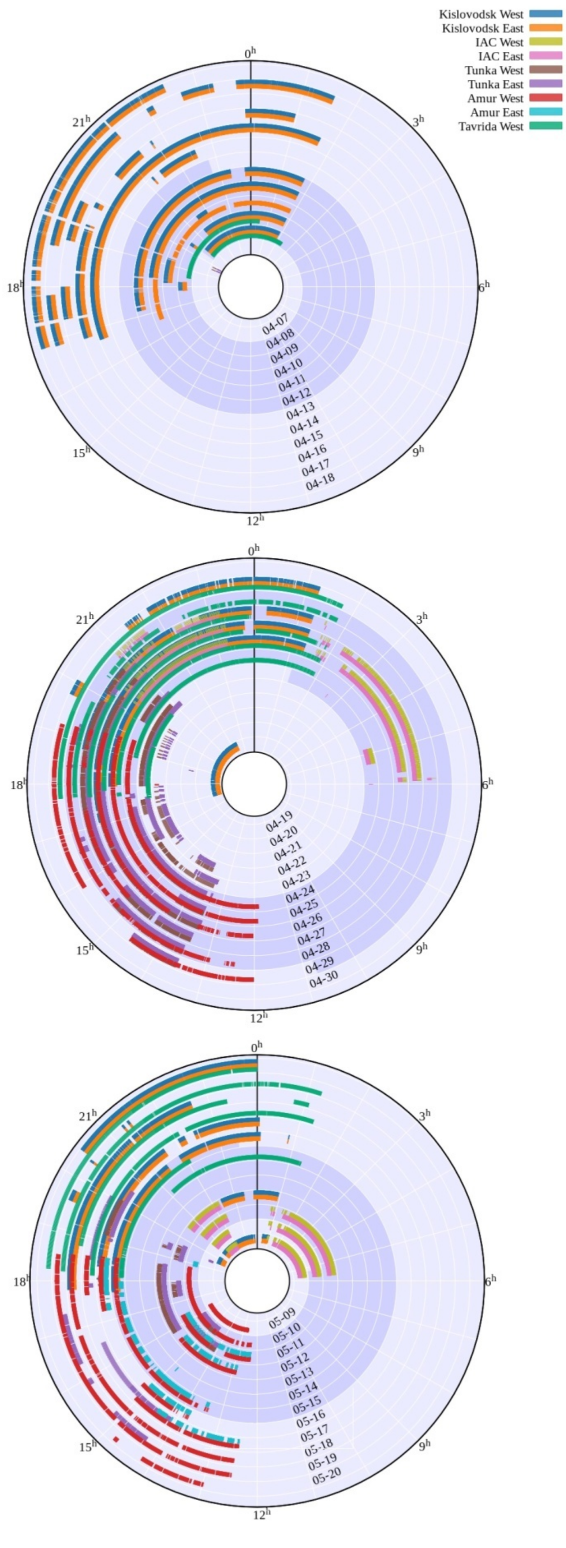

Figure.13. Schedule of synchronous observations of the radio burst FRB180916.J0158+65 by five MASTER telescopes. Darker purple rings show the times of radioburster activity according to ephemeris data (Amiri et al., 2020).
MASTER-Kislovodsk, -IAC, -Tunka, -Amur and –Tavrida data are colored in legend. Our optical monitoring lasted a total of 6 weeks.

However, as in the history of gamma-ray bursts, the phenomenon turned out to be complicated. The impression was created that we are dealing with at least two different classes of sources: unique bursts that never repeat, and repetitive bursts (FRBs). At the same time, we cannot be sure that all "one-time" bursts never repeat.

The leading hypothesis for repetitive radio bursts was the assumption that they are associated with the activity of neutron stars with an extremely powerful magnetic field – magnetars [37,38]. Moreover, it is possible that such magnetars can form both during and after the merger of neutron stars. Until now, no optical telescope has been able to detect the optical glow from the source of the radio burst. The aim of our study was one of the 22 known repetitive radio bursts FRB 180916.J0158+65, recently located with a radio astronomical accuracy of 2 milliarcseconds [32]. Moreover, after the detection of about three dozen radio bursts, it turned out that FRB activity resumes with a period of 16.35 ± 0.18 days [39,40].

In Figure 13 we presented a large-scale optical monitoring of the nearest (at the time of the beginning of our observations) of the fast radio bursts FRB 180916.J0158+65 [32]. In total, with the help of the MASTER telescopes, we obtained about 155,093 images lasted a total of 6 weeks with the total exposure time is 2705058 s (31.3 days).

However, on April 28, at the very height of our monitoring, the robotic telescopes of the MASTER Global Network, monitoring Swift alert signals, automatically began to observe the newly flared galactic Soft Gamma Repeater SGR 1935+2154. On the same day, radio telescopes recorded a short radio burst FRB 200428, and our telescope MASTER-Tavrida [49] obtained the best synchronous optical limit for the emission of SGR/FRB 1935+2154 in the gamma range. Our optical limit shows that X-ray and radio emission are not described by a single power-law spectrum. In the course of our observations using a special technique, we detected a weak glow in the direction of FRB 180916.J0158+65 at a level of 25^m from 1 square second, associated with the extended radiation of the host galaxy.

Along the way, we managed to invent a new method of astronomical observations - a kind of coincidence scheme. In addition MASTER is a double telescope and we guessed to choose only those frames in which there is a signal in both tubes - that's when we got the image of the FRB area in the last photo (Figure 14). Pay attention - the diameter of the MASTER is almost 20(!) times smaller than the diameter of the Gemini.

How did we manage to do this? We took only simultaneous frames received by both tubes almost simultaneously. The most stable frames in terms of quality were obtained with the MASTER-Kislovodsk telescope (Caucasus). We selected the best - there were more than 6000 pairs. Next, from these thousands of pairs, we tried to find such events that simultaneously (that is, during a 10-second exposure) in both tubes consist of three connected pixels, the signal on each should slightly exceed the noise (1.5 sigma). In this case, the nature of the radiation is not important for us at all. Even in the case of aperiodic or periodic pulses according to the coincidence scheme, the reliability of their detection increases sharply. So an experienced amateur astronomer looks at Saturn for a long time, trying to catch the rare moments when the Cassini gap is visible.

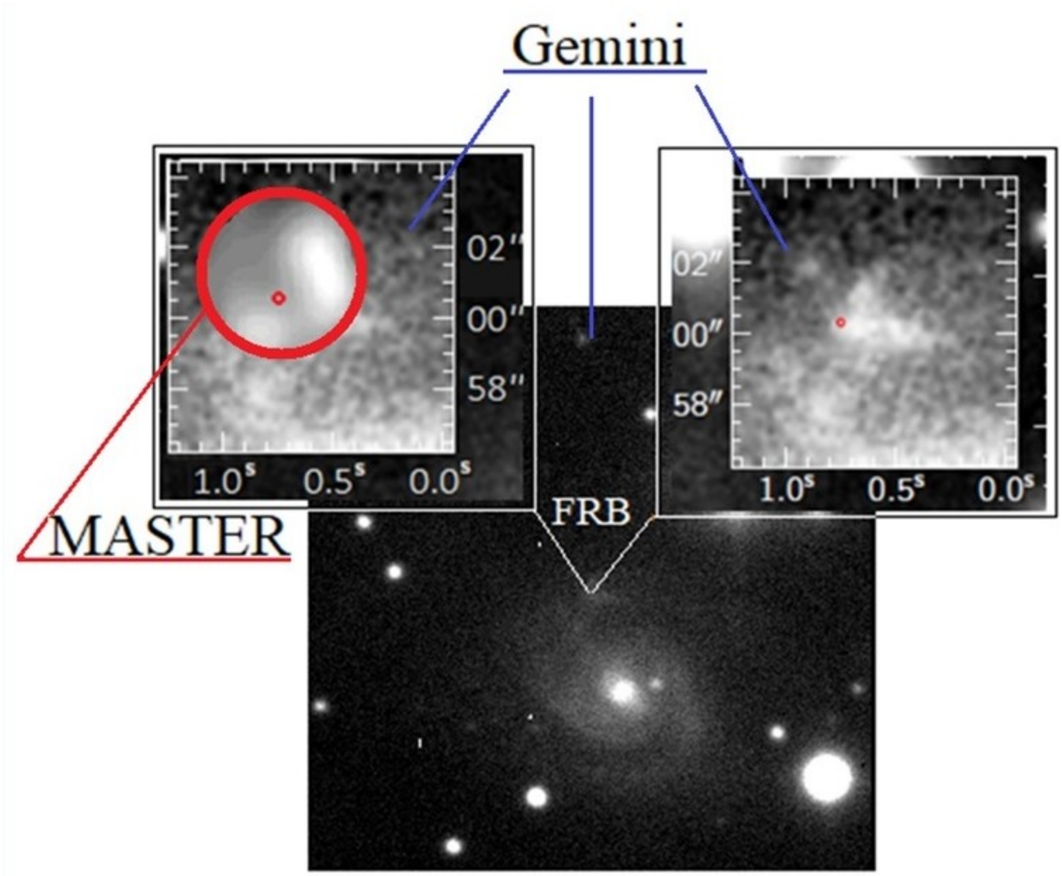

Figure 14.The parent galaxy of the radio burst FRB 180916.J0158+65. In the right square, the fragment of the Gemini image around the position of the radio burst is taken from the public archive ([32] and see Acknoledgments). In the inside of the red circle in the left square you see MASTER synthetic image around FRB [49]. The blue lines show fragments of enlarged region by Gemini for intense star formation around the FRB (red dot).

9. Probing into emission mechanisms of GRB 190530A using time-resolved spectra and polarization studies: synchrotron origin?

Gupta et al. in 2022 [33] present the results of operational (practically synchronous) joint observations of the gamma-ray burst GRB 190530A (Figure 15). A multi-channel international study of one of the most powerful gamma-ray bursts was carried out in a very wide wavelength range from the gamma-ray range to the radio range. It is shown that the most probable mechanism of the glow in such a wide range is the synchrotron radiation of relativistic particles ejected by a black hole forming in the magnetic field of a narrow jet - "jet".

We live in a period of fading N.Gehrel's Swift gamma-ray observatory, when gamma-ray bursts - the most powerful electromagnetic explosions in the universe - were localized even in the gamma range with excellent accuracy. Now in orbit there are mainly wide-angle gamma-ray observatories - Fermi (USA), MAXI (Japan), Konus (Russia). The errors in determining the coordinates in this case are so large that the task of detecting the optical twin (the problem of localization) of the flash is similar to searching for a needle in a haystack and only two optical systems in the world can do it: the Zwicky Transient Factory project is based on a 48-inch telescopes of the Schmidt system (USA) and the Global Network MASTER MSU telescopes are much smaller in diameter. However, our telescopes are located all over the globe, and the american one is only in the USA.Therefore, it is often our nimble telescopes equipped with the most versatile mathematical software in the world that "save" for science such gamma-ray bursts.

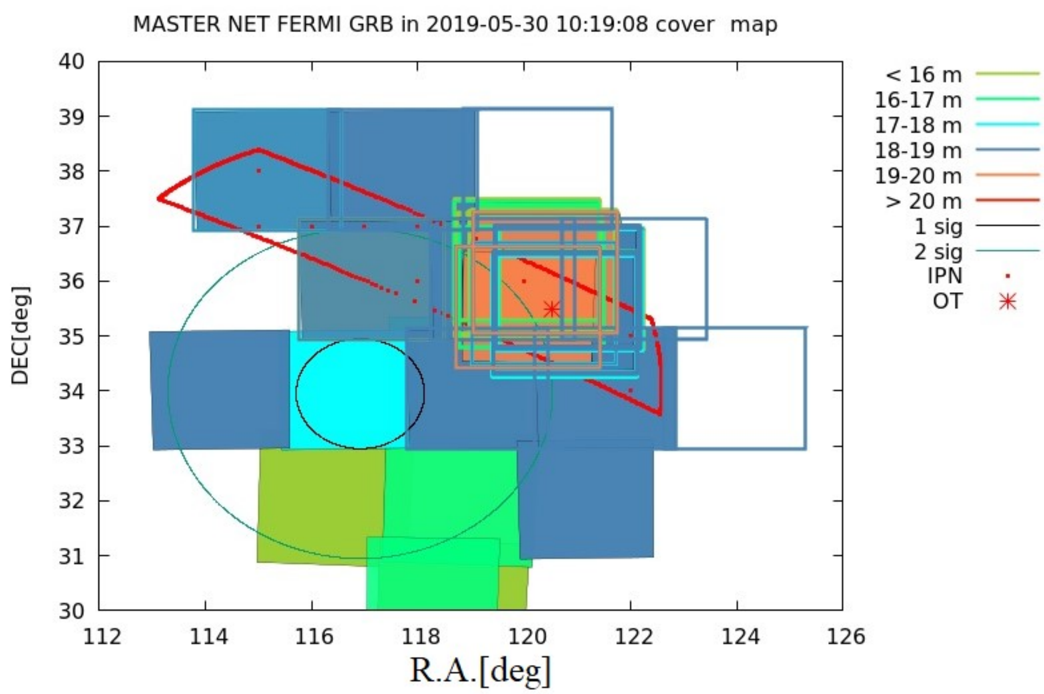

Figure 15. MASTER telescopes network cover map of the GRB 190530A error-field. The squares are the fields of view of MASTER telescopes located on different continents, that observed this GRB. Different colors squares of MASTER telescope field of view (2^0 x 2^0) mark optical unfiltered magnitude limit at every image (see legend). Fermi GBM error-fields are rounds. IPN triangulation error-field is shown by red dots. Optical counterpart position is marked by star[33].

The fact is that a real multi-channel or multi-wave study of giant explosions of the Universe is possible and most effective only if the explosion is localized with optical accuracy! Humanity has the largest telescopes in the world, that have a very small field of view, and if the source of outburst is not localized, then it is, as it were, lost to science. We emphasize that during optical localization, the accuracy of coordinates increases by billions of times.

On Figure 16 we directly shows an optical counterpart image of this super-powerful explosion's at the other end of the Universe taken by the MASTER Global Network. It was thanks to the discovery of MASTER that the 6th most powerful explosion in the Universe recorded by mankind was "saved" and studied!

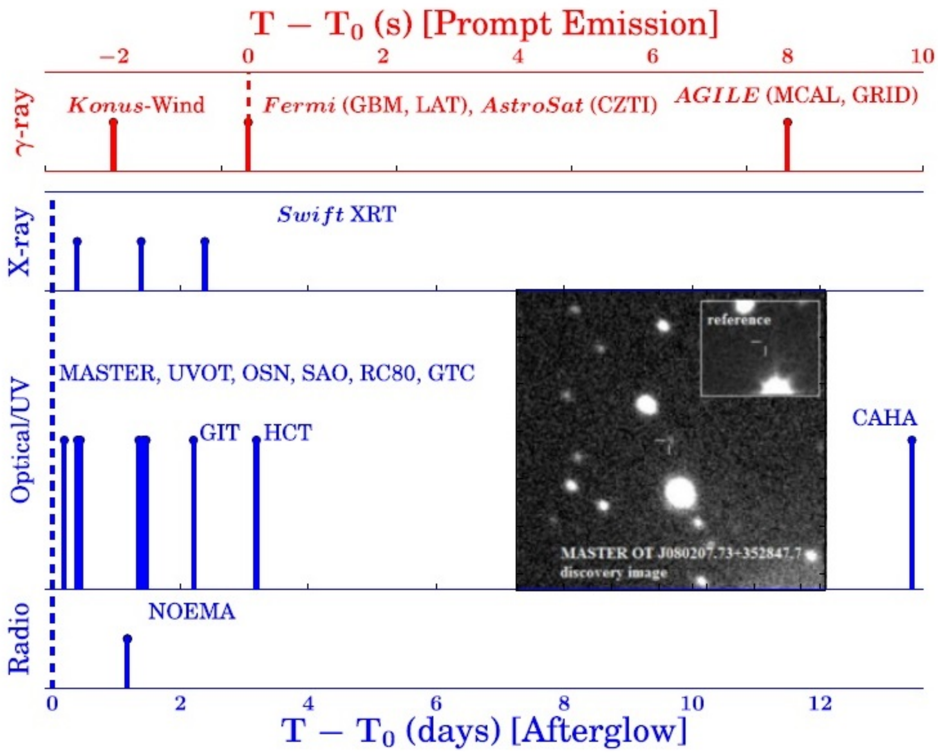

Figure 16. Chronology of events - guidance of various major instruments in gamma-ray, optics and radio astronomy [33].

10. The early afterglow of GRB 190829A

Among the thousands of detected gamma-ray bursts, GRB 190829A (Figure 17)is the fourth closest to us long gamma-ray burst ever detected by the N.Gehrel Swift Observatory (USA) in 15 years of observations and the third confirmed case accompanied by a high-energy particle stream [34].

The reddening of this object does not exceed 8% (Figure 18), and its relativistic sting was definitely directed at our galaxy. This means that the brightness was so great that scientists got a unique opportunity to study in detail the process of the birth of rapidly rotating black holes in the Universe. And as a rule, such an object, a close object, becomes "a classic example from a textbook on the history of black holes."

There is multi-wavelength and multi-channel analyzes of this rare event with a focus on the early stages of its evolution, including Swift's data, MASTER, ALMA (ALMA - Atacama Large Millimetre- Submillimetere Array, Chile) and ATCA (Radio Antenna Array in Australia). Sensitive limits to the linear polarization of optical emission are reported, not in favor of off-axis jet models for explaining the delayed afterglow peak.

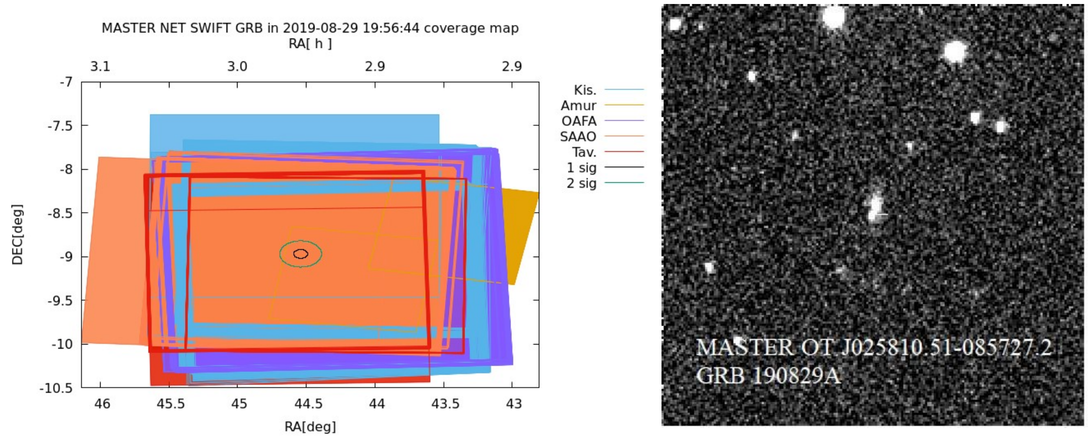

Figure 17. GRB 190829A cover map by MASTER-Kislovodsk, -Amur, -OAFA, -SAAO, -Tavrida tobotic telescopes (left) and optical counterpart MASTER OT J025810.51-085727.2 image (right) . Swift-BAT and XRT error-field position is marked by circles.

The study of multiwavelength light curves and broadband spectra supports the model of at least two separated sources of radiation in a relativistic jet: bright backward shock wave radiation, visible first in optical and X-rays and later in the radio group; and frontal shock wave radiation, predominant in later times and at lower radio frequencies.

GRB 190829A (Figure 17) is an example of classical gamma-ray bursts in a region of the universe close to us.

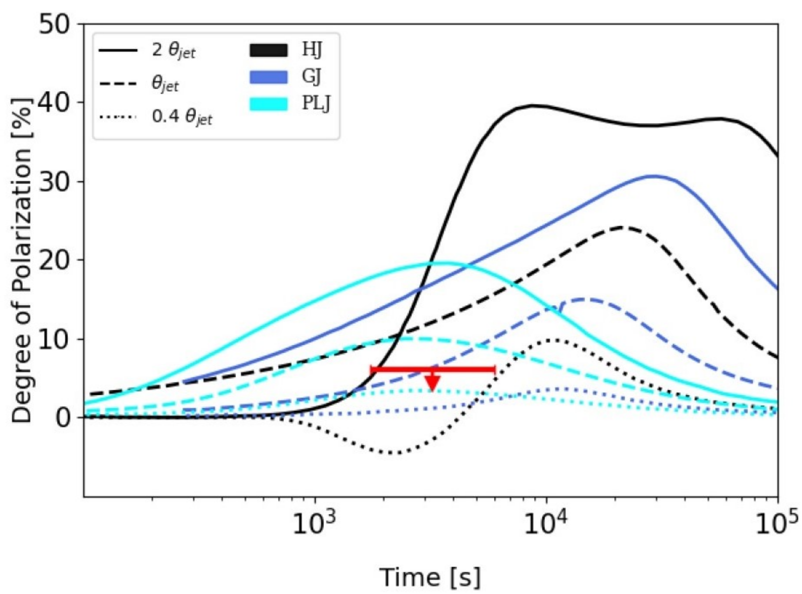

Figure 18 MASTER optical upper limit on linear polarization compared with different theoretical models [34].The red line shows the MASTER limit, which rejects all off-axis models of the relativistic jet - the splash just hit us.

What are we talking about? When we see a standard distant gamma-ray burst, often only one of two regions stands out: the forward (frontal) shock wave and the backward shock wave. As a rule, these areas shine strongly in different ways and it is not possible to immediately see or separate both. The frontal shock wave occurs at the very forward end of the relativistic sting, in the place where the very first eruption of the emerging black hole collides with interstellar gas (or the plasma of the stellar wind of the deceased). In this shock wave, in this most powerful piston of the Universe, high-energy relativistic particles are accelerated, capable of reaching the Earth. They were seen by the HESS installation. However, inside the relativistic jet, the early ejected (flying in front) and slowed down by the environment head of the jet is bombarded by ejected relativistic projectiles, not completely formed black hole. This is how shock waves are born. In general, such an apocalyptic picture was seen on August 29, 2019 by astrophysicists from Russia, the USA, Argentina, Chile, South Africa and Australia.

11. The High Energy Neutrino and Opticaly Anxious Blazars.

The origin of ultrahigh-energy neutrinos has been one of the most mysterious problems of modern physics for the last 10 years [41]. We showed with high statistical reliability that some of the neutrinos detected by ground-based facilities owe their births to supermassive black holes - Blazars, which are in a special anxious state [94]. We have discovered the effect of a rapid decrease in the brightness of the blazar PKS 0735+17 at the time of the unique multiple detection of the high-energy neutrino IceCube-211208A [41-48, 45-48, 51-64] . This rapid (within several hours) decrease in brightness was detected with high confidence (SNR $\approx$ 10) against the background of an anxious multi-day state of the blazar, which was accompanied not only by a maximum increase in the average brightness, but also by an increase in the amplitude of its brightness fluctuations. After that also analyzed all cases of successful observation of blazars around neutrino events and obtained statistically reliable indications of the relationship between neutrino events and blazars in the error squared at the 4.2-σ level.

The first candidate to electromagnetic (EM) counterpart for an astrophysical high energy neutrino event was the blazar TXS 0506+0561 located inside the error box of IceCube-170922A event [35]. When combining the available data suggested that TXS 0506+056 was a very promising high energy neutrino source candidate, the temporal resolution of multi-messenger data did not provide conclusive evidence at the time and the object remained just a likely, but still debatable, candidate. However, the MASTER Global Network was able to detect an unexpectedly fast, within a few hours, anticorrelation: the effect of optical fading of the blazar TXS 0506+056 at the time of neutrino activity .

On the December 8, 2021 at 20:02:51.1 UT, the IceCube Neutrino Observatory detected a high-energy neutrino with a 50% probability of astrophysical origin [42] For several hours around the IceCube-211208A event and three more probable neutrino events from the Baikal Neutrino Telescope , BAKSAN and Arca facilities was detected. According to our data, the blazar PKS 0735+17 was in a dimmed state, against the background of a longer-term increase in optical activity. We also analyzed all cases of successful observation of blazars around neutrino events and obtained statistically reliable indications of the relationship between neutrino events and blazars in the error squared at the 4.2 σ level.

MASTER-Amur optical robotic telescope was pointed to the error box 682 sec after trigger [43] MASTER real time auto detection system [22,23] discovery some brightening flash MASTER OT J073807.40+174219.27,11 coincident with Blazar PKS 0735+17 wich brightening up to 14.1m (0.2m/12h) next nights observations (see Figure 19 with the map of MASTER observations of IceCube-211208A error-box (1σ round is 90% localization error-box (https://gcn.gsfc.nasa.gov/notices_amon_g_b/136015_21306805.amon) radius as detailed in GCN notice, 3σ round is 3 times the radius of 1σ, asteriks is location of PKS 0735+178.

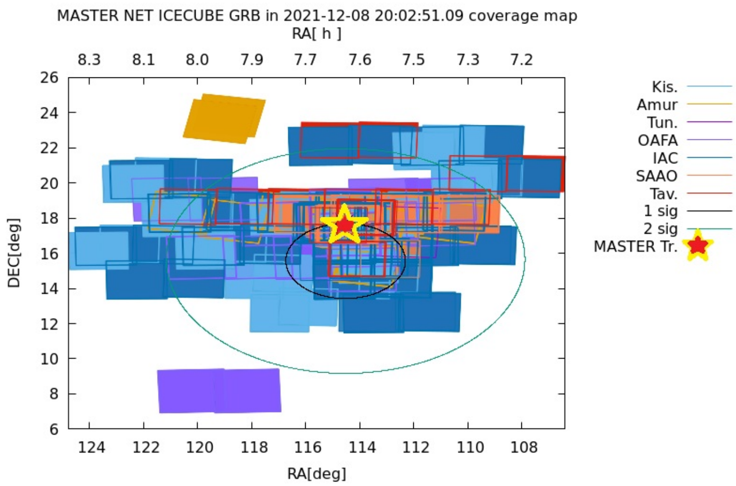

Figure 19. The map of MASTER observations of IceCube-211208A event error-box (1σ round is 90% localization error-box radius as detailed in GCN notice), 3σ circle is 3 times the radius of 1 σ. Asteriks is location of PKS 0735+178.

Afterwards, observations were additionally conducted by MASTER-Kislovodsk, -Tavrida, -OAFA, -IAC, -SAAO and -Tunka (see Figure 20). 8 hours after the neutrino event detection, MASTER-OAFA has imaged blazar PKS 0735+17, located slightly outside the 90% localization error-box. As it turned out, it was flaring at the moment and showed a behavior similar to that of TXS 0506+56 immediately after IceCube-170922A — optical decay before the neutrino event and brightening after it. Observations by other observatories confirmed that the blazar was flaring in gamma, x-ray and radio ranges. One can see the detailed light curve based on MASTER data, as well as ASAS-SN data taken from their Sky Patrol service [62], in Figure 20.

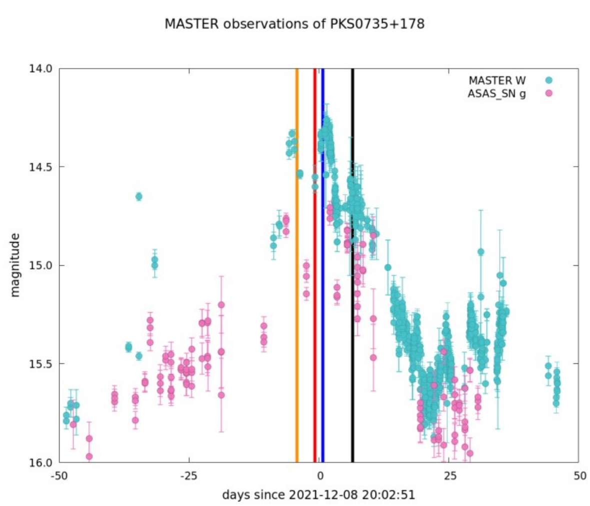

Figure 20. The light curve of PKS 0735+178 for a 100 day period, red line – IceCube and BAIKAL-GVD detection of IC-211208A, orange line – BAKSAN detection, black line – ARCA detections; c - light curve of PKS 0735+178 for a 20 day period, blue dots – MASTER observations, cyan dots – ASAS-SN observations [62].

As inferred from the observations, before the IceCube detection, the blazar has been brightening steadily with small amplitude flares ($\sim 0.3^m$) at a rate 0.025^m per day. A week before neutrino detection, brightening had suddenly accelerated to 0.25^m per day and 2 days after brightening the blazar as suddenly had started dimming at approximately the same rate (0.2 mag per day). Interestingly enough, this behaviour is seemingly symmetrical, as it is repeated in a reversed order afterwards and BAKSAN, IceCube and BAIKAL-GVD detections are located inside the dimming “crevasse”, just like TXS 0506+056 during IceCube-170922A and multichannel observations started [44-48, 51-64].

After the report [53] by Fermi-LAT of a Gamma-ray flaring of the Blazar PKS 0735+178 and the observations in the Ks Band, Carrasco et al. [61] observed the object in the NIR, on December 27th, 2021 (JD 2459575.8069) and found that its fluxes corresponded to J = 13.53 +/- 0.07, H = 12.74 +/- 0.03 and Ks = 12.04 +/- 0.04. The latter is to be compared with the value Ks = 11.57 +/- 0.03 reported in for December 16th, 202124. Our previous NIR photometry for this object (JD2459326.6632) is J = 14.28 +/- 0.07, H = 13.73 +/- 0.04 and Ks = 12.54 +/- 0.03. Our observations are carried out with the 2.1m telescope of the Guillermo Haro Observatory operated by the National Institute for Astrophysics, Optics, and Electronics (Mexico), equipped with the instrument CANICA a NIR camera [61].

Let us discuss the historical light curve of the blazar PKS 0735+178

We made the first photometric observations of this blazar in 2006 with the first robotic telescope MASTER near Moscow [22] After a short break, the blazar was observed regularly and in Fig.21. you can see the historical light curve taken already by several telescopes of the MASTER Global Network. The first conclusion is striking: the registration of neutrinos occurred during the period of a record increase in blazar activity in the entire, almost 20-year history of our observations.

We have tried to quantify the concept of blazar "activity" according to the method proposed earlier for the TXS 0506+056.

The special interest is not even the flux variations themselves, but the rate of their change. To illustrate this, we built a history of the rate of change of the optical flux (Figure 21.). To remove the noise we averaged the close points. Differential flux multiplied by the signal-to-noise ratio.

Thus we introduce a kind of quantitative description of anxiously blazars - the factor of factor of anxiety (FA):

$$FA = SNR \cdot (Fi - Fi\text{-}1)/(ti - ti\text{-}1),$$

where SNR is the $(F_i - F_{i-1})/\sigma$, F_i and σ – is the optical flux and error of two adjacent measurements at the mid-exposure time t_i .

The event of September 22, 2017 has outstanding characteristics in terms of flux derivation and signal-to-noise ratio. We see the same thing in the case to which this letter is devoted.In Fig.21 one can see that the brightness of the blazar PKS 0735+178 reaches its record historical value precisely at the moment of multiple neutrino detection.The repeated discovery of the correlation of neutrinos with optical activity on a short time scale is supported by a statistically reliable result, which will be discussed in the next paragraph.

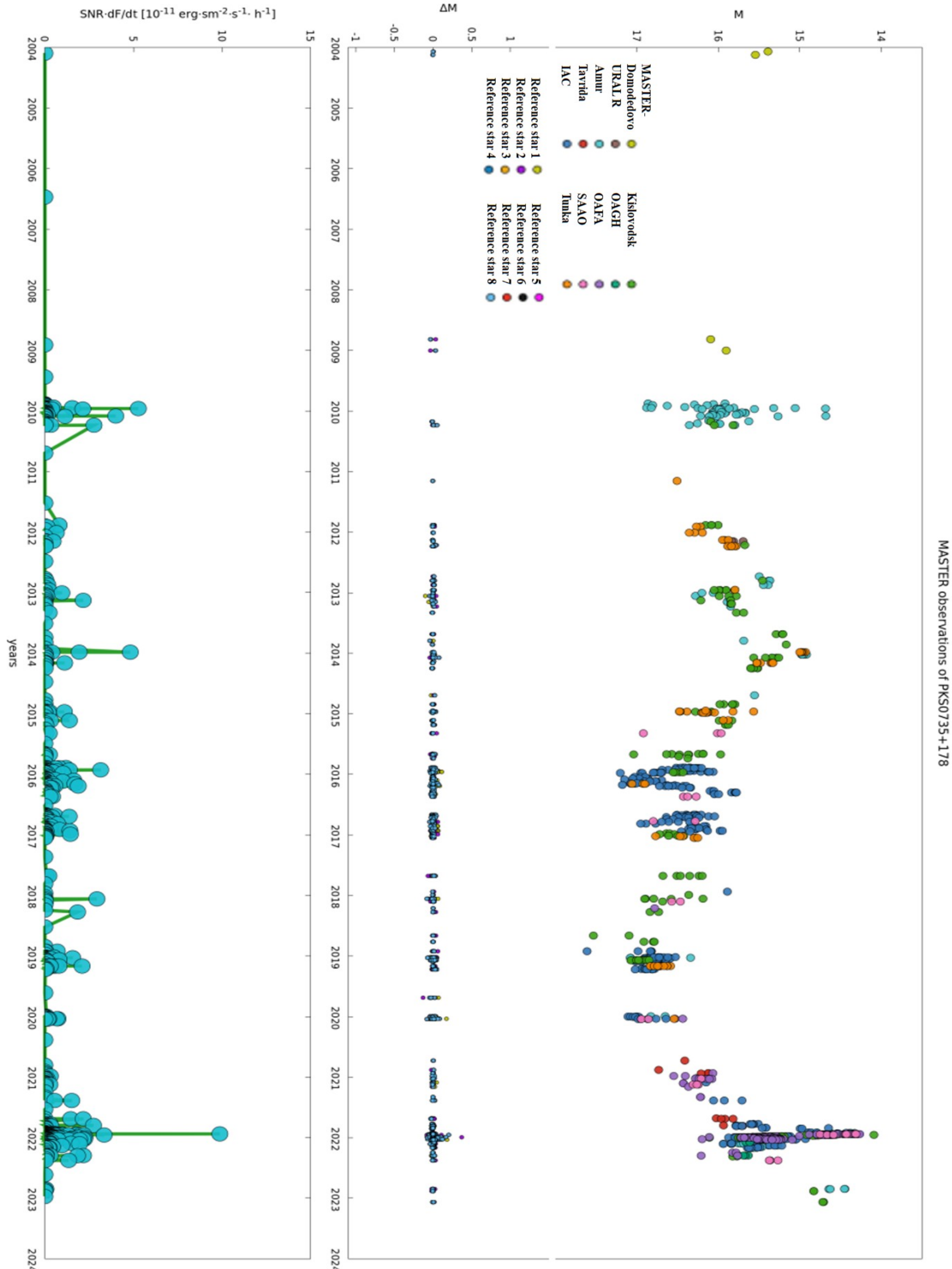

Figure 21 There are: a) the archival light curve based on the observations of the MASTER Global Network and the noise path of 6 comparison stars on the bottom panel, b) the blazar anxiety factor FA.

Our statistical search for optical flares correlation with neutrino events is the following.

MASTER telescopes have been observing IceCube neutrino events alerts since the follow-up of a rare IceCube neutrino multiplet in 2015. In total, since the beginning of 2016 to 1st July 2022 the IceCube Collaboration has issued 106 public alerts. MASTER telescopes have observed 87 of them in the first day after alert receiving. Motivated by the apparent discovery of a neutrino source outside the 90% localization error-box, we arrived at an idea that a number of neutrino sources might be located outside the 90% error-box since it does not take into account a statistical error. To circumvent it, we decided to look for blazar flares in the error-box with twice the size of 90% error-box, i.e., sides of error-box are enlarged by a factor of 2. Such an error-box should correspond to 99.999% localization. As a blazar catalogue, we decided to use Roma-BZCAT as it is one of the more complete blazar catalogues.

As for the factors of picking blazars as neutrino source candidates, we chose detection of «flare». We will call a blazar optically anxious (or in a flare state) if at the moment of observation, its optical magnitude is less than where the median is calculated over the entire observation history of the blazar, and the delta is a number greater than zero which we assumed to be equal to 1m.

We found 4 flares out of 36 blazars visible on our frames near neutrino events with long-term optical light curves, including TXS 0506+056 and PKS 0735+178. Due to low optical brightness of blazars from IceCube error box most of the neutrino events were excluded.

We found 4 flares that were imaged by our telescopes in the first day after neutrino event. These are TXS 0506+056/IceCube-170922A, PKS 0735+178/IceCube-211208A, 5BZB J0201+0034 /IceCube-220225A, 5BZU J0242+1742 / IceCube-211125A. Of them, TXS 0506+056, PKS 0735+178 exhibited both flare and large amplitude variations. Surprisingly enough, 3 out of 4 blazars are located outside of the 90% localization as in AMON notice. If we take into account galactic absorption, 2 of these blazars are at 14^m -15^m and the rest are dimmer than 16^m.

To find whether or not these flares can even be connected to neutrino events, we decided to find a typical background rate for such flares. For that, we analyzed more than 80000 optical observations of 276 blazars from 25th January 2004 to 14th July 2023 combined from MASTER and Cathalina [63] observations. As a result, we found 1452 observations out of 79477, which according to our definition would be classified as flare. Assuming that the observations of blazars were random in time, we get an estimate of the frequency of "random" flare. Comparing this frequency with the frequency obtained for blazars near neutrino events, we get a difference at the significance level of 4.2 sigma.

Using this set of sources, we can estimate an average neutrino detection number from blazars optical flares. Considering that Roma-BZCAT holds 3561 sources and that the average rate of visible background flares is 1452 per 79477 observations of blazars (276 bright blazars) we obtain the average number of 60 optically anxious blazars on the sky at every given moment. Using signalness of neutrino events as a probability of its astrophysical origin we found that 34 out of 87 events are likely astrophysical which means that an astrophysical neutrino arrives, on average, every 47 days. If blazars are responsible for at least a part of measured neutrino flux then the average neutrino detection number from optically anxious blazars is less than $2*10^{-4}$ from optically anxious blazars [94]. This neutrino flux is consistent by an order of magnitude with predictions and with a low number of several detections of one source.

As a result of the analysis of 2 blazars TXS 0506+056, PKS 0735+178 as probable sources of high-energy neutrino events, possible optical manifestations of neutrino flares in blazars were found: a bright optical flare and optical variability at a level of ~ 1^m. It was found that the study of only 90% of localization leads to the exclusion of possible sources of neutrinos from consideration.

Using these facts, a selection was made of 36 blazars from 25 neutrino events, which the MASTER telescopes aimed at on the first day. Of the 36 blazars, 4 showed the behavior expected from neutrino sources: 2 of them were known before (TXS 0506+056, PKS 0735+178), the rest were not considered as neutrino sources.

It was found that 2 of these blazars were very bright (~14^m -15^m) during the event, the rest were much dimmer. These bright blazars also showed a pronounced variability.
Based on this, we assume that the blazars TXS 0506+056, PKS 0735+178 are the likely sources of the neutrino events IceCube-170922A, IceCube-211208A respectively.

At the same time, there is no doubt that the correlation of neutrino events with the activation of blazars in the optical range at times of several weeks and anti-correlation at the time of neutrino detection at times of several hours are consistent with our earlier interpretation in the framework of the process of photonuclear interaction of PeV protons with target potons . Recall that in our model, "PeV" protons accelerated at the front of booster shock waves accelerated by a black hole along narrowly directed jets generate neutrinos with an energy of hundreds of TeV. This occurs through two channels of threshold photon-nuclear reactions:

$$p + \gamma_t \rightarrow \left\langle \begin{matrix} p + \pi^0 \rightarrow p + 2\gamma_{Fermi} \\ n + \pi^+ \rightarrow n + \mu^+ + \nu_\mu \end{matrix} \right.$$

produce neutral and charged pions, which then decay into and gamma-ray photons and muon neutrinos . Both pion-birth reactions are of the threshold type [71].

So π-mesons are born as a result of collision of protons of relativistic jets with photons-targets . In this case, neutrinos and photons of gamma radiation carry away several percent of the proton's energy. Thus, the neutrino luminosity of blazars is determined precisely by the rate of production of charged π+ mesons. The main assumption is that protons accelerated at the front of the shock wave of the relativistic booster are the source of synchrotron optical radiation. Then an increase in the neutrino flux follows, and, consequently, an increase in the probability of its registration should be accompanied by the disappearance of protons in proton-photon reactions. As a result, the optical synchrotron radiation of protons will decrease. The amplitude of the decrease in optical luminosity can reach ~2 times, since the reaction branches proceed with approximately the same probability. This is what we observe.

Returning to our analysis in the previous section, we emphasize the following. Despite the fact that we managed to find 4 blazars-candidate sources of neutrino events corresponding to 4 events, 32 events with unknown sources remain. Even if we assume that most of these events are ordinary noise, then there are about 10 events with an undetermined source (assuming an average signal strength of 30%).

In addition, we must not forget that blazar outbursts occur all the time, and our list probably contains a certain number of “background” blazars. To refine the list, it is necessary to know the rate of blazar background flares, which, unfortunately, requires many long-term observations. Nevertheless, it is possible to find out this rate from the MSU MASTER network data

12. Conclusions

Most of high energy astrophysical sources in the Universe like gamma-ray bursts, high energy neutrinos sources, sources of gravitational waves, fast radio bursts sources can be related events [1-11]. Extreme phenomena still have many problems and have been studied very intensively in recent years [12-86]. The effective ways of their studing involve using multi-channel and multi-wavelength observations by fully robotic telescopes, distributed by Earth for full time control of near and far space like MASTER Global Robotic Net [12-16,19,20,22-27,35,43,47,49-51,67,85-91].

MASTER has large experience in discovery and study of extreme sources in Universe, from the latest there are the following:

- the discovery of significant and variable linear polarization during the prompt optical flash of GRB 160625B [13],[27];
- the detection of a strong evidence for high energy neutrino progenitor of the neutrino event IceCube-170922A [35] and alert and follow-up observations of hundreds high energy neutrino error-boxes, triggered by IceCube and ANTARES detectors including the largest input to optical support of an IceCube multiplet (triplet) IceCube--160217 [85,86];
- the detection of three-stage collapse of the long gamma-ray burst from GRB 160625B prompt multiwavelength observations, the optical counterpart discovery and a structured jet explains the extreme GRB 221009A [27];
- MASTER-OAGH installation in December 2021 [89,90], the 9th MASTER observatory for GRB, GW, FRB and high energy neutrino sources investigations;
- the first detection of an orphan burst at the rise phase and the detection of the GRB time [20];
- the most input to the optical support of gravitational wave events, detected by aLIGO and LIGO/Virgo during O1-O3 observational runs , including the first one GW 150914 ([82]-[85]) and independent optical detection of the first LIGO/Virgo Neutron Star Binary Merger GW170817-Kilonova MASTER OTJ130948.10-232253.3/SSS17a ([14]-[17]) that let us the first in history gravitational-wave standard siren measurement of the Hubble constant with LIGO/Virgo collaboration [87];
- the first large optical monitoring campaign of the closest at that moment radio burster FRB 180916.J0158+65 simultaneously with a radio burst [85];
- multiwavelength flare observations of the blazars , including study of the flat-spectrum radio quasar NVSS J141922-083830 and observations of S5 1803+784, TXS0506+056 blazars ([29],[50],[77]-[80]);
- the discovery of the new type of calibration for gamma-ray bursts, called smooth optical self-similar emission, in which some of their class can be marked and share a common behavior, so we identify these subclasses of GRBs with optical light curves described by a universal scaling function [81];
- the discovery of several dozens of optical counterparts of gamma-ray bursts, including the nearest GRB 180728A, the brightest GRB 190530A, GRB 161017A and investigation of several thousands of GRB error-fields, detected by Fermi, Swift, Konus-Wind, LomonosovMAXI, Integral , for example GRB191221B, GRB 160625B,

GRB 221009A, GRB 181201A, GRB 190114C, GRB140629A and other [13,14,26,27,33,34,49,81,85,88] ;

- the shape of the asteroid (conical) calculation and the rotation period of 5.9 hours detection as the results of white-light photometry for a uniquely long series of data (13.5 hours of observations, 1124 measurements) for the Near-Earth Asteroid (NEA) 2015 TB145 [91].

The main goal of our research is the study of extreme phenomena of the Universe. We are talking about processes, that, in terms of their power, approach the power of the Big Bang and go into the modern era and will be continued.

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