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Global MASTER-Net Highlights.

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There are some of the results of the MASTER Global Robotic Network over the past few years.In gamma-ray astronomy these highlights includes optical GRB counterparts discovery, for example MASTER OT J131034.94-214304.8 with a structured jet explains the extremely luminous GRB 221009A, MASTER OT J131034.94-214304.8 detection of extremely luminous GRB 230204B with the GRB's jet structure and surrounding environment investigation, three-stage collapse of the long gamma-ray burst from GRB 160625B prompt multiwavelength observation, the discovery of significant and variable linear polarization during the prompt optical flash of GRB 160625B, the first detection of an orphan burst at the rise phase, 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, 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. In gravitational wave astronomy our results includes the 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, and independent optical detection of the first LIGO/Virgo Neutron Star Binary Merger GW 170817 - Kilonova MASTER OTJ130948.10-232253.3/SSS17a that let us the first in history gravitational-wave standard siren measurement of the Hubble constant with LIGO/Virgo collaboration. The distance for GW170817 event was predicted by our Scenario Machine.

In neutrino astronomy MASTER highlights includes the detection of a strong evidence for high energy neutrino progenitor of the neutrino event IceCube-170922A, i.e. the blazar TXS0506+056 optical variability at trigger time; the detection of blazars PMN J2345-1555, PMN J0328-2329, 5BZB J2256-3303 blazars variability near ANTARES high energy neutrino detection times during the multiwavelength follow-up campaign by MASTER Between MASTER highlights are also the discovery potentially hazardous asteroid Svarog(2015 UM67), the new method for exoplanet detection in MASTER big data archive of wide field images and other.

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1. Introduction. Extreme Universe by MASTER.

The main goal of our research is the study of extreme phenomena in the Universe. We are talking about the processes that, in terms of their power, approach the power of the Big Bang and go into the modern era [1-105]. MASTER Global Robotic Telescopes Network was designed for optical observations for the high energy astrophysics events. The gamma-ray bursts (GRB), gravitational wave bursts (GWB), high energy and ultra high energy neutrino sources (UHE), fast radio bursts (FRB) sources and other are in the field of MASTER interests and were investigated last years. Between the latest results are the following:

- the discovery of significant and variable linear polarization during the prompt optical flash of GRB 160625B [13],[27];
- 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 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 blazars PMN J2345-1555, PMN J0328-2329, 5BZB J2256-3303 blazars variability near ANTARES high energy neutrino detection times during the multi-wavelength follow-up campaign of ANTARES by MASTER. In the error field of ANTARES-150901 event there is a possible source of high-energy neutrinos globular cluster M4 (NGC6121, V = 5.8m), in which the millisecond radio pulsar PSR B1620 − 26 A (at distance 3.8 kps with the period 11.075 sec) is located. The globular cluster itself does not generate ultra-high energy particles, but a millisecond radio pulsar can do it, because a radio pulsar is a magnetized neutron star that is an accelerator of relativistic particles. Neutrinos themselves are not accelerated, but charged particles are accelerated. The pulsar can accelerate a charged particle to "PeV" energies and, if it collides with the nucleus of an ordinary atom, then the neutrino will be born. The origin in the globular cluster of the nucleus of an ordinary atom is explained by the presence of the exoplanet PSR B1620 − 26 b around the radio pulsar PSR B1620 − 26 A [95,86];
- 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 OT J191303.43+194623.1 discovery of enormous energy ($E_{iso} \approx 10^{55}$ erg) and proximity (z = 0.15) GRB 221009 [96];
- MASTER OT J131034.94-214304.8 detection of extremely luminous GRB 230204B with the GRB's jet structure and surrounding environment investigation [97];
- Multiwavelength analysis of one of the closest (z = 0.0785) long GRB 190829A optical counterpart MASTER OT J025810.51-085727.2, discovered at extrimelly high zenith distance 88.7 degrees [34,103]

- Gamma-ray bursts at extremely small fluence investigations [98];
- The discovery of a new object MASTER OT J044907.58+705812.7 (AT2024aaf, dwarf nova outburst) and study of a number of transients [100];
- The detection and investigation of exoplanets with MASTER Global Network Telescopes
- the first detection of an orphan burst at the rise phase (MASTER OT J123248.62-012924.5) and the calculation of the GRB time by of the by smooth optical self-similar (SOSS) emission, with interpretation of the nondetection of gamma-ray emission at space observatories in terms of the hypothesis of a ``failed'' GRB. This was the first detection of a non monotonic orphan burst optical transient emission [20];
- 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] ;
- MASTER-OAGH installation in December 2021 [89,90], the 9th MASTER observatory for GRB, GW, FRB and high energy neutrino sources investigations;
- *the discovery potentially hazardous asteroid Svarog(2015 UM67);*
- 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].

2. Theory base.

After the discovery of his equations, Albert 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. In 2016, Einstein introduces a new universal physical quantity, in the form of a combination of two fundamental constants, the speed of light and the gravitational constant, and calls it natural luminosity : $L_E = c^5/G = 6 * 10^{59}$ erg/sec.

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:

$$m_p = \sqrt{\frac{\hbar c}{G}} \approx 2.176434(24) \cdot 10^{-8}\ \text{kg}$$

$$t_p = \frac{L_p}{c} = \sqrt{\frac{\hbar G}{c^5}} \approx 5.391247(60) \cdot 10^{-44}\ \text{s}$$

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 (see *Lipunov, 1992* [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 1 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 there is 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.

In the Universe, the processes of collisions of relativistic stars - neutron stars and black holes are actually going on. These densest objects in the universe collide in minimal time and are able to emit a decent fraction of their resting energy in a split second.

$$t_{min} = R_g/c = 3\ km/\ 300000\ km/s \sim 10^{-5}\ s$$

In fact, relativistic stars participate in orbital rotation and fusion is not a head-on collision. For two neutron stars, the phase lasts a couple of milliseconds after, and black holes are an order of magnitude and a half larger and, accordingly, emit gravitational waves at frequencies of hundreds of hertz.

Neutron stars are the first class of astronomical objects whose existence has been predicted theoretically (Landau, 1932). V. Baade and F. Zwicky linked the formation of these objects

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with the Supernova explosion and directly pointed to the Supernova remnant of 10^{54} in the Crab Nebula, where after a third of a century a radio pulsar was discovered with a rotation period possible only for neutron stars (Baade, Zvicki, 1934). In 1966, Y. Zeldovich and I. Novikov found a physical process that could make these microscopic objects with a radius of about 10 km bright sources of electromagnetic radiation (Zel'dovich, Novikov, 1966). This mechanism is the accretion of ambient gas onto a neutron star. In 1967, I. Shklovsky used it to explain the nature of the brightest X-ray ScoX-1 source. Earlier, N. Karadashev and F. Pacini found another source of energy for a magnetized neutron star - this is its rotational energy stored during the collapse (Kardashev, 1964; Pacini, 1967). Thus, neutron stars born at the tip of the pen became a scientific hypothesis directly confirmed after the discovery of radio pulsars (Hewish, Bell, Pilkington, 1968) and X-ray accreting pulsars (Giacconi, Murray, Gursky et al., 1972). After the discovery of the double radio pulsar (Hulse, Taylor, 1974), it became clear that the neutron stars were colliding in the Universe, since the merger time of the components of this pulsar was less than Hubble time (Brumberg et al., 1975).
How often do macroscopic reactions occur in the universe?

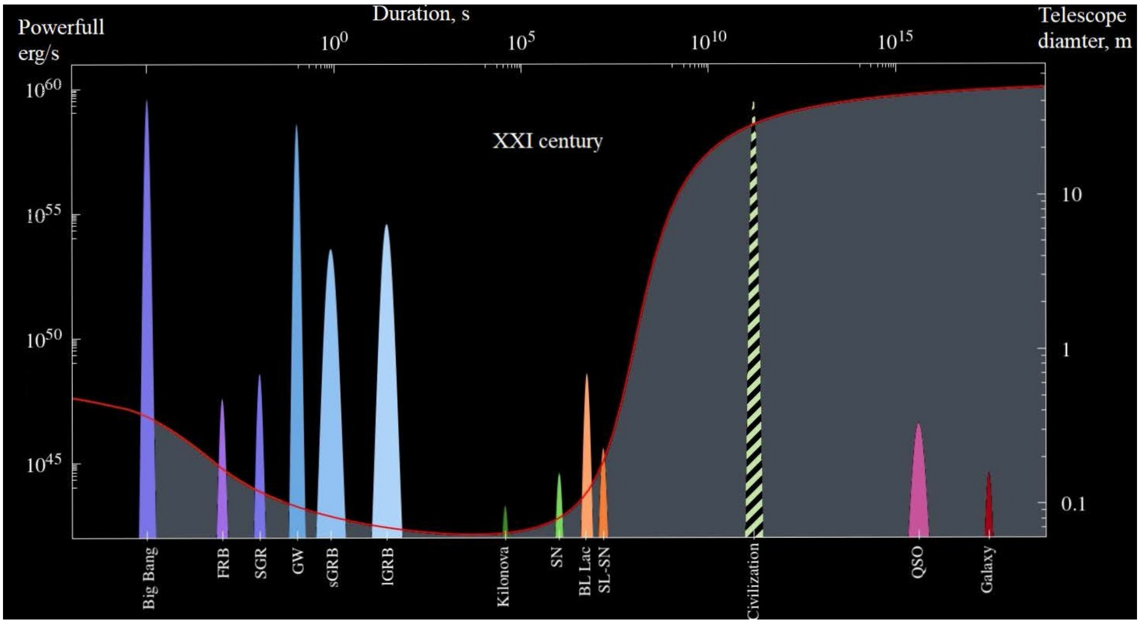

Figure. 1 The Universe in XXI centure in 5th dimension. The figure qualitatively shows the luminosities of the brightest objects in the Universe (lower axis) to maximum luminosity (left axis) on a logarithmic scale depending on their lifetime (upper axis). It turns out that the brightest objects of the 20th century universe are hundreds of billions of times weaker than what can be in nature (left side of the diagram). 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.

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.

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?

3. The Prediction of the distance to the first kilonova.

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In the early 80s of the last century, we came up with a special computer code "Scenario Machine" (see Kornilov & Lipunov in1983 [2], Figure 2 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.

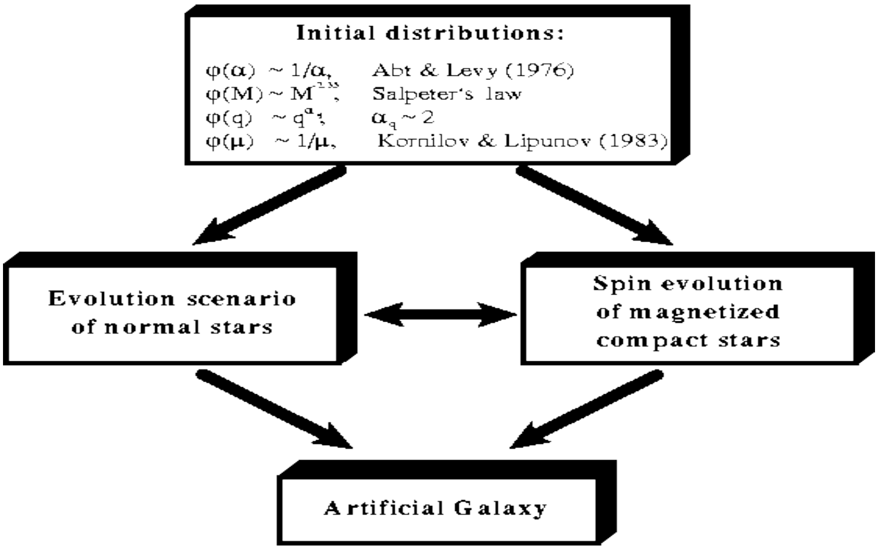

Figure 3. The block diagram of the Scenario Engine looked quite simple.

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).

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. 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:

NS + BH -> GWB + BH+GRB +KN ~1/100 000 years (by Lipunov, Nazin, Panchenko in 1995 [6])

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 [104].

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 1995 [10]).

There is another type of reaction that can potentially lead to powerful gravitational-wave radiation involving heavy O-Ne-Mg-white dwarfs [105]:

$$WD + WD \geq GWB + SNIa + NS, \text{ if } M_{OV} > 2M_{Ch},$$

$$WD + WD \geq GWB + SNIa + BH, \text{ if } M_{OV} < 2M_{Ch}.$$

where M_{Ch} is the Chandrasekhar limit, and M_{OV} is the Oppenheimer Volkov limit.

The first calculation of the frequency of such events showed that up to 1 event per year can be expected within a radius of 20 Mpc. These first estimates were periodically confirmed by our calculations on a more and more advanced Scenario Machine (Lipunov, Nazin, Panchenko et al., 1995; Lipunov et al., 1997a,b,c; Lipunov & Pruzhinskaya, 2014 [6-9, 104]).

For example, in an article entitled "The Gravitational Wave Sky" (Lipunov, Nazin, Panchenko et al., 1995 [6]) with using the Scenario Machine, a map of the probability distribution of detection of neutron star merger events across the sky with an integral pace of 3 events per year was built.

The Multimessenger GW170817 / GRB170817A discovery of the merger of two neutron stars on 17th August 2017 accompanied by a gamma-ray burst and an optical kilonova event is a triumph of the ideas about the evolution of the baryon component in the Universe. Despite the current uniqueness of this observation, the variety of the experimental data obtained makes it possible right now to draw important theoretical conclusions about the origin of the double neutron star, its merger, and the subsequent flare-up of electromagnetic radiation. We demonstrate that the discovery of the merger at a distance of 40 Mpc is entirely consistent with the very first calculations of the Scenario Machine [3]. In modern terms, the predicted rate is ~10 000 Gpc-3 (Figure 3) [16].

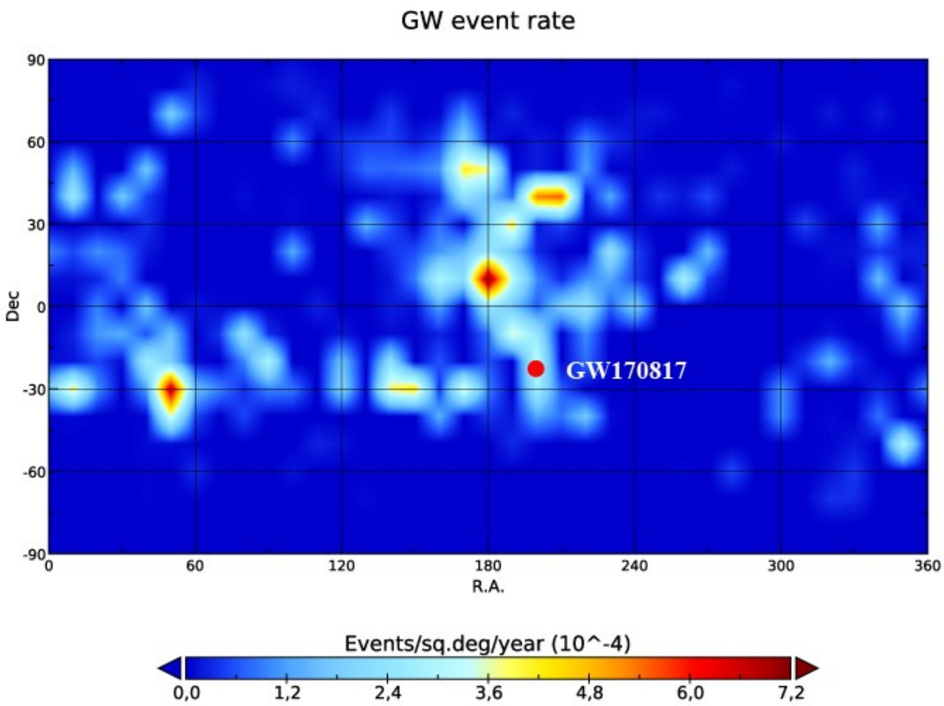

Figure 3. The Probability map of neutron star collisions in terms of the number of merger events per 1 square degree in galactic coordinates. Total number of mergers up to 50 Mpc ~ 3 events per year (Lipunov, Nazin, Panchenko et al., 1995b)

In addition, after the merger of neutron stars, an object remains - either a light black hole (BH) or a heavy neutron star. It all depends on the properties of nuclear matter. Kilonova - an optical flash accompanying the merger of neutron stars was predicted by Blinnikov et al. (1984) and was later named Kilonova (Li & Paczyński, 1998).

One of the last works released before the discovery of gravitational waves was summed up by 20-year calculations using the Scenario Machine of the rate of fusion of neutron stars. The result of this work, which generalized our estimates, was a graph of the dependence of the frequency of mergers on distance, it shows that the probability of mergers of neutron stars in the nearest vicinity is a few events per year.

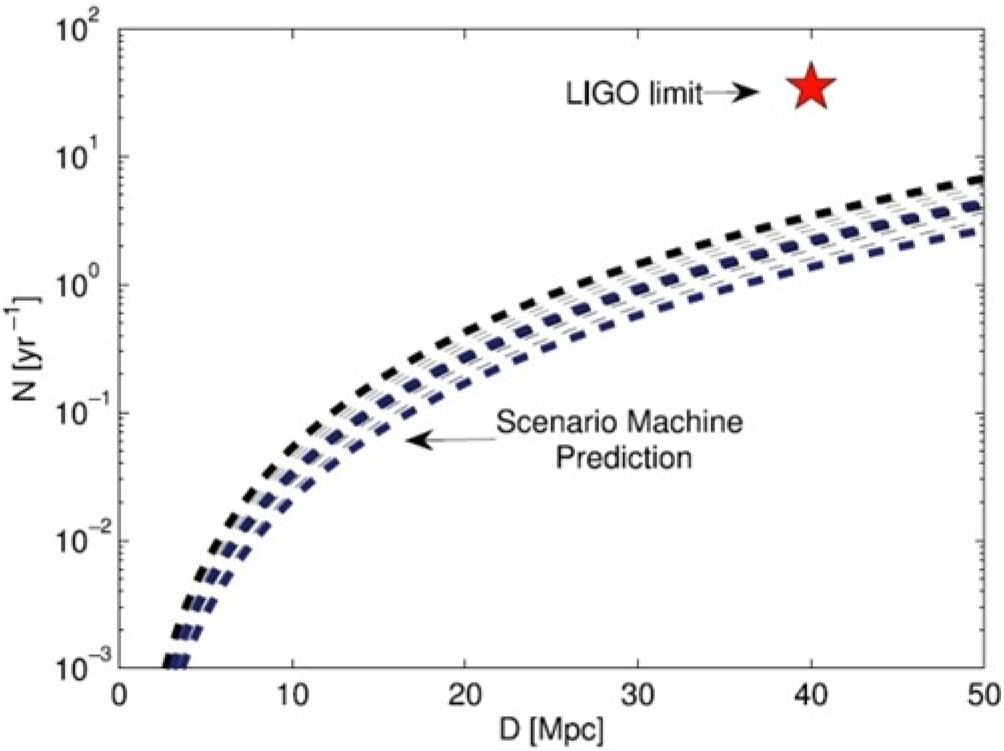

Figure 4. The number of NS+NS mergers per year inside the sphere of distance D in terms of the Scenario Machine prediction for kick velocities in the 100–150 km s−1 interval [104]. The black and blue curves correspond to modified Salpeter (1955) and Baldry & Glazebrook (2003) IMF, respectively. The asterisk shows the LIGO S6 limit (Abadie et al. 2012) [104].

The gamma-ray burst is more like a laser pointer beam. But Kilonova, although it is millions of times weaker than the gamma burst, is omnidirectional and will not fly past us. For example, calculations in 1995 showed that on average inside 50 Mpc you can expect 3 events per year. Therefore, in 2002 we began experimental confirmation of our calculations.

4. 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]), orphan bursts discovery, the independent discovery of the kilonova GW170817 (Lipunov et al. in 2017 [14-17]) and other (see introduction).

At the beginning of the 21st century, it became obvious that the use of robotic observatories in astronomy makes it possible to make a breakthrough in the study of sharply unsteady and short-lived phenomena in the Universe. With the help of robotic observatories built in developed countries, it was possible to discover their own optical radiation of the most powerful explosions in the Universe - gamma-ray bursts. The discovery of tens and hundreds of supernovae made it possible to suspect the existence of the so-called "dark" energy or cosmic vacuum energy. The relative availability of small telescopes makes it possible to increase the efficiency of observations, increasing their number and placing them in different geographical points. Russia, as the longest country in the world, is an indispensable place for such research. The first Russian robot telescope MASTER was created in 2002 and installed near Moscow (V.M. Lipunov et al. 2007). The MASTER network was further developed in 2008-2010, when 4 observatories were put into operation, equipped with MASTER II telescopes and cameras beyond a wide field of view. And, since 2012, the MASTER network has become global, and already in 2016 we installed three overseas observatories in South Africa, the Canaries and Argentina. At the end of 2021, a similar complex was installed in Mexico. The position of the MASTER global network nodes during GW170817 historical follow-up campaign is shown in Figure 4.

Figure 4. The map of MASTER Global Robotic Net and Ligo/Virgo collaboration interaction in GW 170817 investigation. The flags are MASTER telescope nodes and Ligo/Virgo ones.

The MASTER II telescope network (Lipunov et al., 2010) reveals more than 10 types of astronomical objects. MASTER network is used to solve the following observation tasks: Localization and synchronous polarization observations of gamma-ray bursts; Localization of gravitational-wave bursts; Operational observations and search for the source of neutrinos of high and ultra-high energies; Observations and localization of fast radio burst (FRB) sources; Search for supernovae, new and explosive variables; Discovery of dangerous asteroids, comets;

Registration of orphan bursts. The interaction of MASTER telescopes and grande physical experiments are shown at Figure 5.

Figure 5. MASTER and Grande Physical Experiments.

5. Gravitational waves

5.1 The First successful optical localization of a gravitational wave source

This subsection will describe the optical localization of the collision site of neutron stars using the example of an independently detected optical flash of Kilonova in the galaxy NGC 4993 (Lipunov, Gorbovsky, Kornilov et al., 2017). We believe that it is the optical localization of the GW gravitational-wave event that is the key moment in the formation of gravitational-wave astronomy. This circumstance is understandable to any astronomer, after he calculates the effectiveness of optical localization in comparison with localization in other channels available to astronomers of the world after August 17, 2017. LIGO/VIRGO detectors, as well as data from Fermi and INTEGRAL gamma-ray observatories and amounted to about 100 square degrees. The square of the errors of optical telescopes was about 1 square seconds, that is, 3,600,3600,100 = 1 billion times less! The importance of optical localization is well understood by gamma-ray astronomers, who for more than 25 years could not understand where gamma-ray bursts come from until they could identify the burst with the optical afterglow.

After the discovery of the gravitational-wave pulse GW170817 / G298048 by three LIGO/VIRGO antennas (Abbott et al., 2017), the MASTER global network telescopes after a gamma-ray burst received the first independent images of the galaxy NGC 4993, in which an optical transient was later discovered SSS17a / MASTER OT J130948.10-232253.3 (AT2027gfo) - LVC GCN 21529 (Coulter et al., 2017a); LVC GCN 21546 (Lipunov et al., 2017), apparently representing Kilonova after the merger of two neutron stars.

The multichannel discovery of the merger of neutron stars on August 17, 2017. GW170817 / G298048 / GRB 170817A, accompanied by an outbreak of gamma radiation and optical Kilonova, is a triumph of ideas about the evolution of the baryon component in the

Universe. Despite the current uniqueness of this observation, the variety of experimental data obtained allows us to draw important theoretical conclusions about the origin of the binary neutron star, its merger and the subsequent outbreak of electromagnetic radiation.

The merger on August 17, 2017 occurred at a distance of 40 Mpc, which is fully consistent with the very first calculations of the "scenario machine" [6,104]. Now we can state the birth of a new science - gravitational-wave astronomy

5.2 Observations of the error field of the gravitational wave event GW 170817

Since the first detected gravitational wave event on LIGO interferometers (Abbott et al., 2016, Lipunov, 2016), the MASTER global network of robotic optical telescopes has been actively involved in the search for optical emission of all detectable LVC events (Lipunov et al., 2016).

On 17 Aug 2017 at 12.41pm, 06.47 with UT (Von Kienlin et al., 2017) reported that the Fermi-GBM recorded a short (2s) gamma ray pulse that occurred 2s after the LVC GCC gravitational wave pulse was recorded (GCN 21505, 21506).

The first optical localization of the event GW 170817 literally after half a day reduced the uncertainty in the coordinates of the source of the gravitational-wave burst by hundreds of millions of times. Despite the uniqueness of this event, the variety of experimental data allows already right now to draw important theoretical conclusions about the origin of a binary neutron star, their merger and the subsequent outbreak of electromagnetic emission. Operational diagram of interaction of MASTER robotic telescopes with LIGO/VIRGO gravitational wave antennas. By August 2017, that is, two years after the detection of the first gravitational-wave pulse GW 150914, the interferometer of the European gravitational-wave project VIRGO, located near the city of Pisa (Italy), joined the two American antennas. The first message about LIGO/VIRGO G298048 came during the day to many MASTER-net observatories. Only on the MASTER-Amur (Far East, Russia) there was a night time, but observations were impossible due to weather restrictions. The MASTER network began to observe the LIGO/VIRGO G298048 error field on August 17, 2017 at 17 hours 06 minutes 47 from UT. MASTER-SAAO automatically began to observe the total area of the initial LIGO/BAYESTAR error field obtained through socket connection (GCN 21505), and Fermi/GBM (GCN 21506) error fields automatically immediately after sunset at 17:06 UT on August 17, 2017, i.e. 15 943 s after the LVC event time (12 hours 41 min 04 from UT). The first unfiltered images (usual inspect series of 2 images of 180 seconds) had an 19.0m upper limit. This first image also covereds IceCube's most likely candidate No. 4 (GCN 21511), but optical transient (OT) was not found in this field. Then MASTER-SAAO continued to observe the initial field of the Fermi and LVC alerts.

The final LIGO/VIRGO G298048 localization map (GCN 21513) came at a time when a new small (compared to the previous one, but still comprising a huge 125 square degrees) error field was under the horizon for MASTER-SAAO in South Africa and MASTER-IAC in the Canary Islands. Only for the MASTER-OAFA telescope in Argentina, the error field was above the horizon, but it was still light. So, MASTER-OAFA at the Felix Aguilar Observatory (National University of San Juan, Argentina) has begun an inspection of the updated localization region (error-field). Observations began from the first field in the position of R.A., Dec.(2000) = 12h 59m 00.00s -19h 59m 38.0s. The cover map and position of Kilonova SSS17a/MASTER OT J130948.10-232253.3 and NGC 4993 region are at Figure 6a,b.

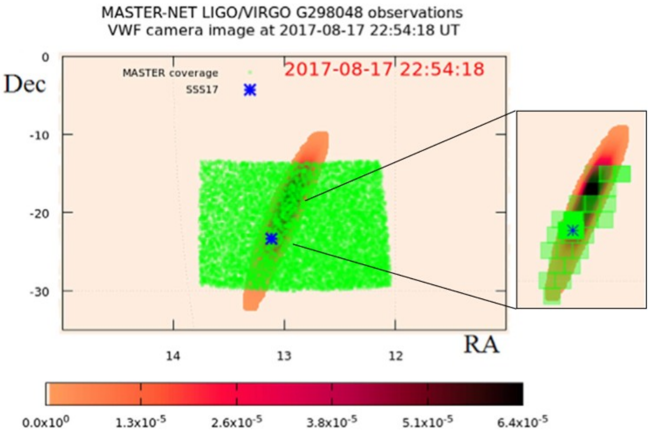

Figure 6a. Event on 17 Aug 2017 at 10.58pm with UT. SSS17a/MASTER OT J130948.10-232253.3 Orange oval - error field of gravit wave event; green square - covering of error field with SHOCK MASTER-OAFA camera (VWFC) [14].

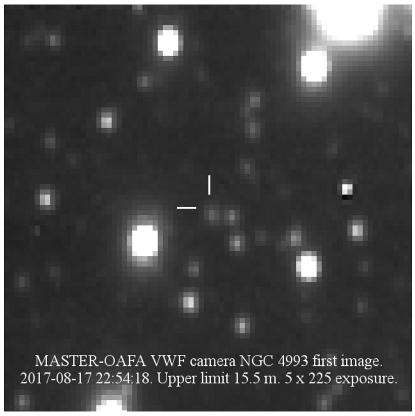

Figure 6b. The first image of the NGC galaxy 4993 10 hours after the GW 170817/G 298048 event ин MASTER-OAFA very wide field camera [14]

The first observation of host galaxy started by MASTER very wide field cameras (a complete analogue of the shock cameras installed in the Lomonosov space observatory with a field of view equal to 2 × 380 square degrees, 22 arcseconds in a pixel [22,23] on the same mount). As a result, a large series of images of MASTER-VWF cameras was obtained with a 5-second exposure and with almost no temporary delay of all LIGO/VIRGO BAYESTAR-HLV G298048 errors, including the galaxy NGC 4993. MASTER-SHOCK cameras have a huge data stream - 200 GB/day. Therefore, we could not store all the images for a long time. Single (5 sec) images of the VWF camera taken during MASTER-II exposure (typically 180 sec) and CCD reading (~ 30 sec) are automatically summed and stored in the archive. Since the MASTER-OAFA telescope began an inspection survey of the LIGO/VIRGO G298048 error field fairly close (< 10 degrees) to the position of NGC 4993, this position was covered by almost all images of the SHOCK camera during this inspection survey. To get the deepest possible early observation of NGC 4993, we further summarize the first six additional sets of images, given that the region falls in different parts of the frame. As a result of adding 225 single images of the MASTER-SHOCK camera with an exposure of 5 s (total exposure - 1125 s), it was possible to obtain the first image of the galaxy NGC 4993 after the merger with a ~ limit of 15.5^m .

Starting at 22 h 54 min 18 from UT, the galaxy NGC 4993 is visible in these combined images. For the analysis, we used reference images of the galaxy from our archival images from previous nights, with the same upper limit. After subtracting images with reference images, we found no OT in the direction on NGC 4993 with a V-magnitude limit > 15.5. The error-field of LVC G298048 localization BAYESTAR-HLV quickly sank under the horizon, so MASTER-OAFA had only ~ 3 hours to inspect it. Starting at 22 h 58 min 48 from UT on 17 Aug 2017, MASTER-OAFA tested a new BAYESTAR-HLV (GCN 21513) localization map with unfiltered images (180 s exposure) and an upper limit of 19-20m. The upper limit for adding images increases to 20.5m.

The final BAYESTAR-HLV localization map is strongly elongated along the declination axis. Therefore, different parts of it went to the horizon at different times. The special program "MASTER-planner" program distributed the sequence of filming in such a way as to have time to cover the maximum possible probability within this map before the regions go under the horizon. In this particular case, only one MASTER-OAFA telescope worked on the localization map, but the "MASTER planner" is configured to cover the error area of the GW network of telescopes as quickly as possible. MASTER-OAFA, unlike other telescopes of the MASTER network, is a single-tube telescope. Therefore, to prevent white spots on the coverage map, MASTER-OAFA always takes two adjacent pictures (imitation of a double telescope). The coverage was inspected on the first night from the beginning of observation until the last possible field inside the BAYESTAR-HLV localization map disappeared beyond the horizon.

During this inspection survey, at 23 h 59 min 54 from UT on 17 Aug 2017, i.e. 11 h 18 m 50 s after LVC actuation, the MASTER-OAFA robotic telescope, regardless of any optical information, took two images with the galaxy NGC 4993 from Kilonova SSS17a/ MASTER OT J130948.10-232253.3, the discovery of which was published later. Kilonova is clearly visible on the difference between the current (2017-08-17) and reference images (Figure 7).

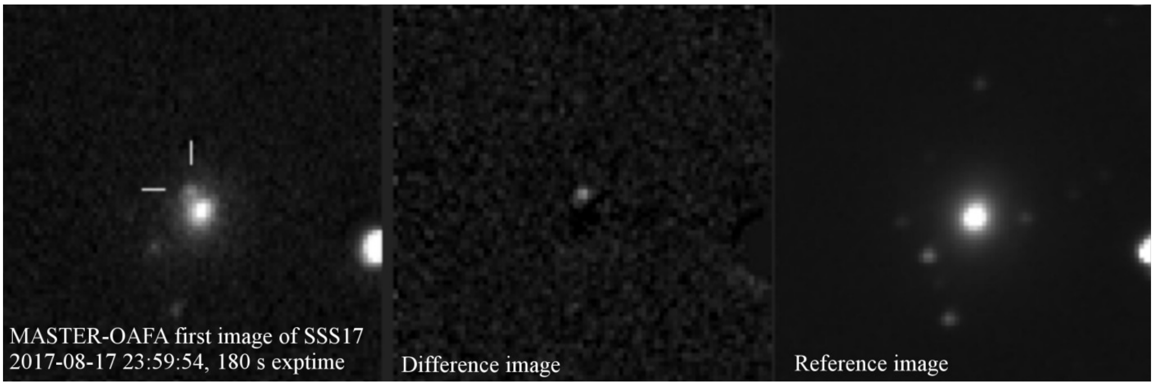

Figure 7. The Kilonova image (left) at host galaxy and the difference between the 2017-08-17 MASTER image and reference MASTER one [14]

The software of the MASTER network is constantly being improved and for some objects for which several indisputable criteria for automatic verification can be distinguished, the publication of discoveries occurs automatically.

Observations of event G298048 took place when it was deep night in Moscow, and this RT was found in the database only on the morning of August 18, i.e., a few hours after another team reported it (LVC GCN 21529) (Coulter et al., 2017). Since the optical source was found, the MASTER telescopes stopped surveying inside the LIGO/VIRGO probability map and focused on observations SSS17a/MASTER OT J130948.10-232253.3 (Fig. 7.13). Over the next three days, both the southern telescopes MASTER-SAAO (South Africa) and MASTER-OAFA (Argentina) monitored the Kilonova SSS17a/MASTER OT J130948.10-232253.3 in the galaxy NGC 4993 in white light in filters B and R.

As a result, until August 1, 2017, MASTER-SAAO and MASTER-OAFA took more than 600 images of the SSS17a/MASTER OT J130948.10-232253.3 area. It should be emphasized that the main article (Abbott et al., 2017a) on the first ever localization of a gravitational wave source was written by more than 1000 co-authors, most of whom are members of the LVC community. Nevertheless, in this article there are only about ten key co-authors who represent teams that made a decisive contribution to the localization of the source of gravitational waves and had the right to make corrections at the publication stage. Among them, for example, teams of six optical telescopes, which received images of Kilonova before the first publication of her coordinates, and they had the right to publish individual articles. Not everyone took advantage of this right and printed their articles. But the MASTER network team wrote such an article, published it and scored more than 170 citations in several years (Lipunov et al., 2017g). There you can also find detailed photometry of Kilonova on the MASTER telescopes.

There are archival images of the MASTER Global Network of the galaxy NGC 4993 from January 17, 2015 from 00 h 45 min 46 from May 2, 2017 to 22 h 17 min 04 s. See the MASTER archive image table at: URL:
http://master.sai.msu.ru/static/MASTER_G298048_PREDISCOVERY1.txt

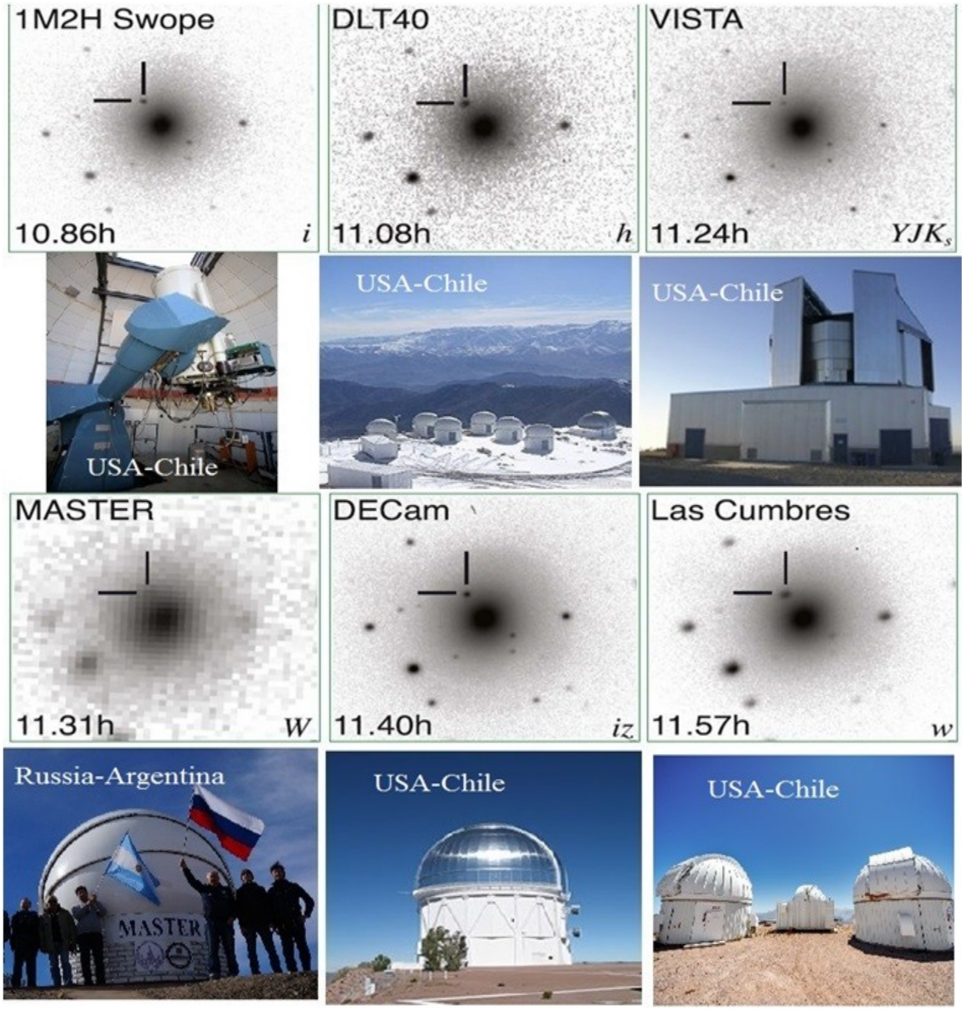

Figure 8. Six telescopes that independently received an image of Kilonova GW170817. Between the first and last time peo telescope went 43 minutes.

Now there is already the fourth epoch of gravitational-wave detectors work in the international collaboration LIGO-VIRGO (-KAGRA), nevertheless, the first successful optical localization of the GW170817 event remains unique. Why does optical localization turn out to be fundamentally important for natural science, and why has luck accompanied only one case on August 17, 2017? The answer to the first question is quite simple. Most of the events recorded by GW had large localization region with uncertainty, up to a thousand square degrees into which hundreds of thousands of galaxies fall even after taking into account the distance of a known object, determined with errors with errors of 10-20%. And only in the case of the event of August 17, 2017, associated with the merger of neutron stars, the GW error field reached 30 square degrees, it was possible to find a kilonova flash and localize the source with astronomical accuracy. At the same time, 5 other of six telescopes (Figure 8), which were publishied as independently discoverers of Kilonova, used a list of bright ~ 30 galaxies included in the spherical segment with a ~ of 40 Mpc and a thickness of about 10 Mpc. Only one telescope had a wide field of view (FOV ~ 4 square degrees) and used its usual method of sequential inspection of the the whole localization error - it was the MASTER-OAFA Global Network telescope located in Argentina [14].

5.3. GW 170817 on Theoretical Gravitational-Wave Sky Map

In 1995, the first theoretical map of the probability distribution of mergers of neutron stars was constructed using the morphological catalog of nearby Tulley galaxies, as well as population synthesis of relativistic stars [6,10,18]. It was assumed that in elliptical galaxies located at a distance of < 50 Mpc, star formation ended long ago. In spiral and irregular galaxies, the specific rate of star formation was considered constant and equal to the rate observed in our Galaxy ($1M_\odot$ / year /10^{11} $M_\odot$) multiplied by the mass of the Galaxy. We reproduce the results of these calculations indicating the location of the first detected neutron star merger in the galaxy NGC 4993. Optical localization of gravitational wave sources.

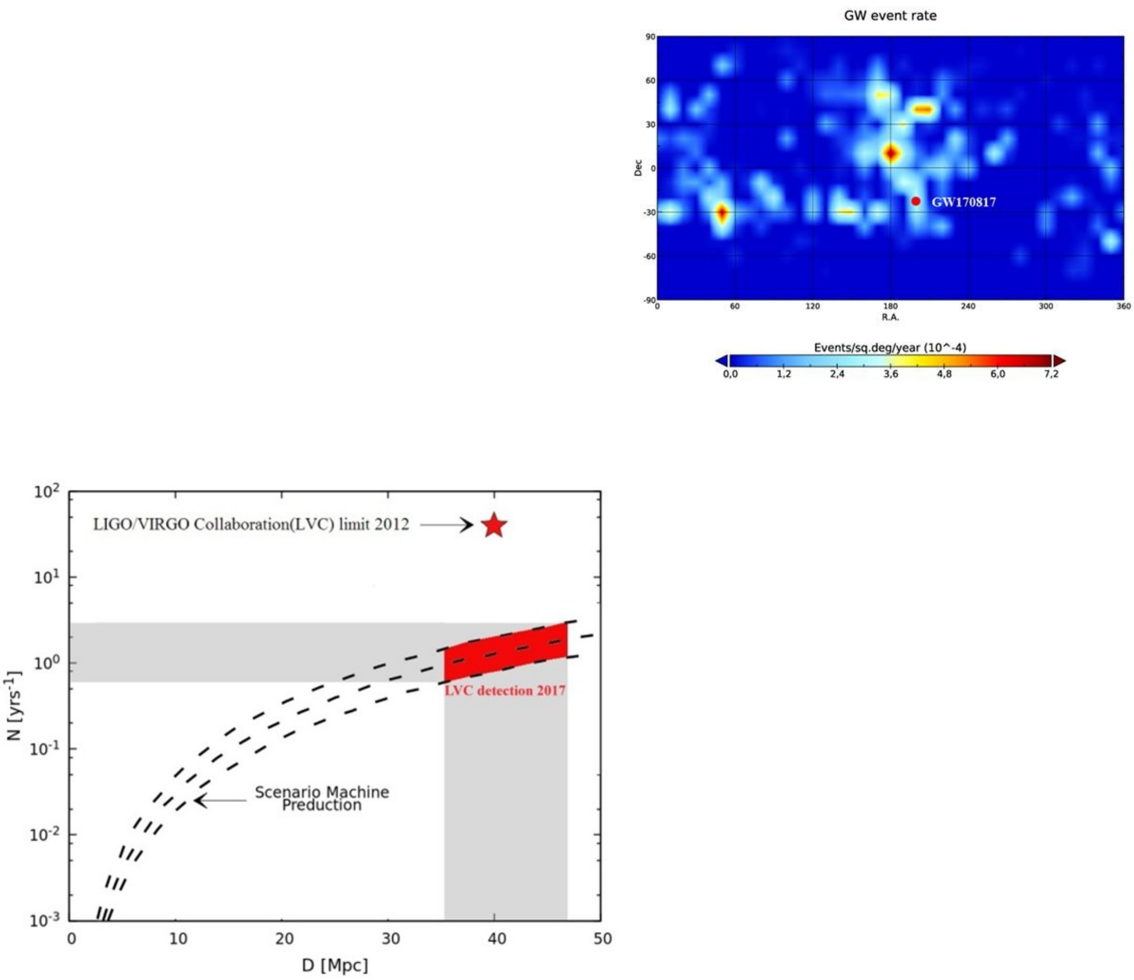

Figure 9. The merger rate of the neutron stars as a function of the size of the sensitivity horizon [16] and The Probability map of neutron star collisions. The red box is the GW 170817 NS's merging in NGC 4993 [15]. The distance to the event GW170817 is shown by the shaded region. The distance to NGC 4993 was measured using the Tully-Fisher method, D TF = 41±5.8 Mpc . The asterisk shows the LIGO S6 limit [103].

6. Gamma-ray bursts

6.1 The Discovery of the polarization of the prompt optical radiation of Gamma-Ray Bursts

When we started MASTER robotic telescopes development in 2002, it was immediately aimed at solving a world-class problem. One of the most important unsolved experimental problems of the science of gamma-ray bursts is the task of observing the effects by the nature of a relativistic thin jet through which the energy of a rotating collapsing substance is channeled. Such a "sewer" could be a large-scale magnetic field, along the lines of force of which the flow of relativistic particles accelerates and moves. Detecting the polarization of the gamma-ray burst radiation while the central machine is still working would directly indicate the presence of an ordered magnetic field. And this polarization was registered in 2016.Intrinsic radiation of gamma-ray bursts is called optical radiation, which occurs as a result of the operation of the central machine and is usually observed synchronously with gamma radiation. Since the explosion lasts less than a few minutes, such observations are a complex scientific and technical problem that was solved at Moscow State University when building the MASTER Global Network of Robotic Telescopes.

On June 25, 2016, at 22 hours 40 minutes 16 seconds of universal time, the Enrique Fermi Space Observatory recorded a burst of gamma radiation, which later turned out to be just a harbinger of a real giant flash. Despite large errors in the primary coordinates of the gamma-ray burst, the entire localization region fell into the very-wide field cameras (VWFC) of the MASTER-IAC telescope 131 seconds after the first message, the Fermi registered this event itself with sufficient coordinate accuracy. Later, the Crimean MASTER-Tavrida of Lomonosov Moscow State University, a new node of the Global Network at that time, joined 12 seconds after receiving the updated coordinates at 22 hours 44 minutes 30 seconds, received the first frames. As a result, the MASTER Global Network not only shot the entire film with ultra-wide field cameras (MASTER-VWFC) about the explosion with the best time resolution, but also for the first time in the history of gamma-ray burst research recorded the polarization of the optical radiation of the gamma-ray burst at the moment when the flash was still ongoing.

The gamma-ray burst of GRB160625B turned out to be one of the most powerful cosmic explosions of this type, which arose in a narrow stream of relativistic particles accelerated by the electromagnetic field of a fast-rotating black hole formed before our eyes at the other end of the Universe.

The detected polarization of its own optical radiation directly showed that the vent of the most powerful space gun is formed by an ordered powerful magnetic field formed by the resulting black hole. The discovery of minimum polarization ($\Pi_{L,min}$), measured in four different temporal bins (red squares), remains fairly constant over the first three exposures, then increases by 60% during the fourth (and last) observation presents at Figure 10a. At the same time, an evident increase in the γ-ray count rates (grey shaded area; 5-second time bins) marks the onset of the third episode of prompt emission. The spectral shape and fast temporal variability observed during G3 are typical of a GRB's prompt emission [13]. For comparison, there simultaneous polarimetric measurements of the three brightest stars in the MASTER-IAC field of view.

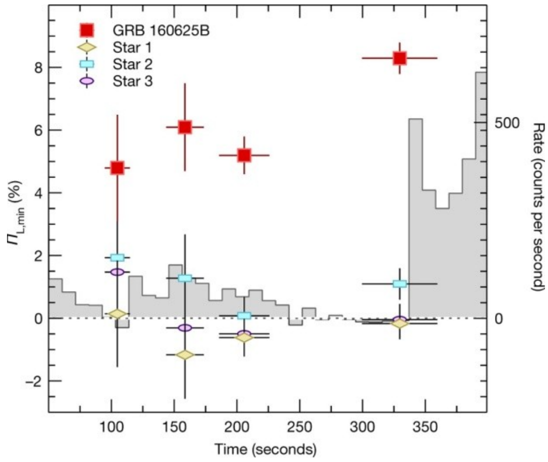

Figure 10a. The discovery of minimum polarization ($\Pi_{L,min}$), measured in four different temporal bins (red squares), remains fairly constant over the first three exposures, then increases by 60% during the fourth (and last) observation. For comparison, we also show simultaneous polarimetric measurements of the three brightest stars in the MASTER-IAC field of view (error bars represent 1σ) [13].

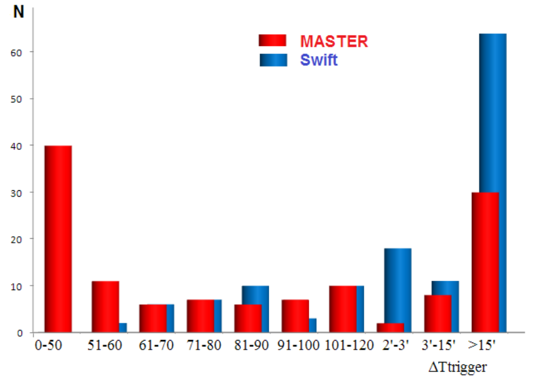

Figure 10b. Histogram of the guidance speed of the MASTER (red) and Swift-UVOT (blue) telescopes for 130 gamma-ray bursts considered in [88].

6.2. GRB earliest optical observations by MASTER and Smooth Optical Self Similar Emission (SOS Similar Emission)

Due to the unique advantages of the MASTER, we have the opportunity to obtain and study detailed light curves of gamma-ray burst sources in the optical range. The MASTER is the leader in the first pointing on gamma-ray bursts (Figure 10b). Among 130 studied localization regions, an optical companion was found in 44 cases (see Table 20 in [88]).

In the paper [81], a new type of gamma-ray burst calibration (GRB) has been proposed in which some class of gamma-ray bursts having a common behavior can be distinguished. We call this behavior Smooth Optical Self Similar Emission (SOS Similar Emission) and identify this subclass of gamma-ray bursts with the optical light curves described by the universal automodel function. We drew the attention of researchers who have been studying the most powerful explosions in the Universe for half a century - gamma-ray bursts, to the fact that there is some universal optical glow that occurs either during the gamma-ray burst or immediately after its end. Moreover, we found a coordinate system in which the light curves (the behavior of flash brightness over time) are universal in nature and are similar to each other as Siamese twins.

Obviously, all curves have a universal shape (see Figure 11). What is their nature? A common feature of the light curves in Figure 11 is their very smooth brightness change. i.e., all lightcurves have a smooth rise, a smooth peak, and a smooth decline without discontinuities and spikes fading into each other. As can be seen from these curves, their time and energy characteristics are quantitatively different from each other, and the times and amplitudes of the maxima are more than two orders of magnitude, respectively.. The flows are normalized by maximum flow and time at maximum moment by formula $m - m_{max} = -2.5\lg(F/F_{max})$, $\tau = t/t_{max}$ To eliminate the effect of time dilation due to cosmological redshift, we use a dimensionless variable equal to the time elapsed since the beginning of the gamma ray burst divided by the delay of the maximum optical flux, i.e. $\tau = (t - t_0)/(t_{max} - t_0)$. We take $t_0 = t_{trigger}$ (the trigger time) almost everywhere. Optical light of gamma-ray bursts that meet our criteria are presented at Figure 11 [105]. It is clear that the curves differ by hundreds of times in flux and time. For all selected events, we use $t_0 = t_{trigger}$, although the trigger on the gamma-ray detector could have been triggered by a precursor or vice versa after the burst onset. The MASTER Global Network telescopes have discovered and/or obtained the earliest photometric data for 8 out of 11 suitable optical sources of gamma-ray bursts for analysis: GRB170202A, GRB060605A, GRB080810A, GRB 100906A, GRB121011A, GRB140629A, GRB080710, GRB071010 and GRB150413A, GRB 180316A, GRB 181213A, AT2021lfa

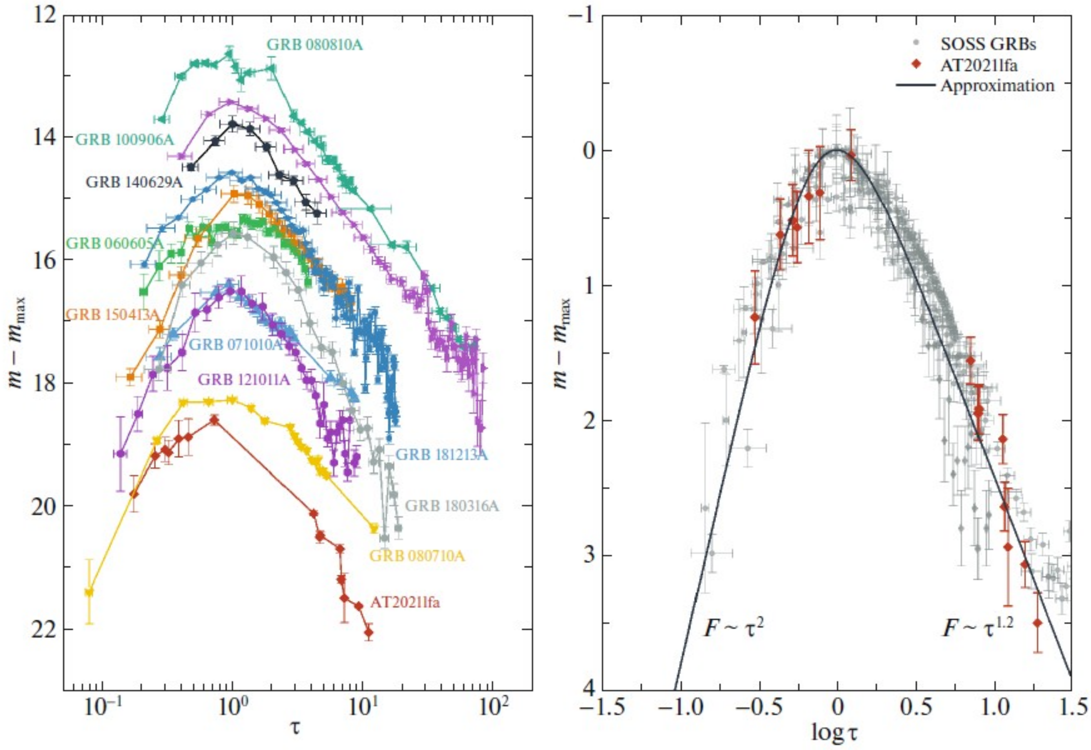

Figure 11. Optical light curves (apparent ma*gnitude versus time since the* burst trigger was detected) of gamma-ray bursts that meet our criteria [105] at the left side and Universal SOS emission with orphan burst AT 2021fa, detected by MASTER. Red points are orphan burst observation from [105].

The paper [81] proposed a phenomenological formula:

F=F$_{max}$*(*[illegible] , where *F* is optical flow, [illegible] *~1.2* , [illegible] *2.71 ≈ e*, [illegible] *= (t-t*$_0$*)/(t*$_{max}$ *- t*$_0$*)*.

The universal appearance of optical lightcurves found from our analysis fits well with predictions of a jet or fireball model penetrating the environment (Mészáros & Rees 1997). At the boundary of the fireball, a shock wave appears, compressing the surrounding substance. Electrons of compressed gas accelerate to a relativistic velocity and cause synchrotron radiation, which is observed in the form of afterglow. In addition to the front shock wave, there is also a reverse shock wave propagating in the expanding primary shell. This process is short, but the

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synchrotron emission of electrons heated in the wave contributes substantially to the overall flux at the early afterglow stage. Sometimes that contribution dominates.

The presence of a reverse shock wave explains the wide variety of morphological features of the light curves. Indeed, the dynamics and emission of the reverse shock wave depend on the magnetic properties of the relativistic jet and its thickness along the motion [105] and whether the medium is interstellar or wind. Recall that the shell is thin if, upon reaching its inner border, the reverse strike remains non-relativistic. In a random sample, you can hardly expect the same properties of a fireball. Therefore, the light curves of different bursts can vary greatly (and often have two peaks [105].The universal appearance of optical lightcurves found from our analysis fits well with predictions of a jet or fireball model penetrating the environment. At the boundary of the fireball, a shock wave appears, compressing the surrounding substance. Electrons of compressed gas accelerate to a relativistic velocity and cause synchrotron radiation, which is observed in the form of afterglow. In addition to the front shock wave, there is also a reverse shock wave propagating in the expanding primary shell. This process is short, but the synchrotron emission of electrons heated in the wave contributes substantially to the overall flux at the early afterglow stage. Sometimes that contribution dominates.

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6.3 Gamma Ray Bursts as the Dark Energy Probe

For the first time, the idea of using GRB, taking into account the cosmological evolution of the rate of their formation, to detect Dark Energy was carried out in 1995. Scenario Machine calculations show that GRB can potentially constrain the cosmological parameters[18]. Even for the simplest models we used, late epochs of galaxy formation ($z_0 < 2$) do not seem to be consistent with the observed GRB log N - log S distribution.

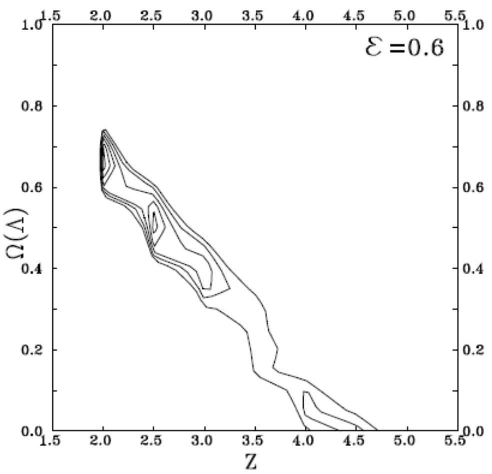

Figure 12. Probability distribution on Ω(▮▮) (dark energy density) of z_0 redshift at maximum star formation rate in Universe [18].

The best model we obtained by fitting to the 411 GRB available from the 2nd BATSE catalogue (Meegan et al. 1994) corresponds to z_0 = 2.2, ⤢ = 0.5 (the ratio of the number elliptical to spiral galaxies) and 👂▮▮= 0.75, with a 95% agreement according to O2-test (we also used a Kolmogorov-Smirnov test; both criteria give qualitatively similar results). We also note that the earlier epochs of the primordial star formation are not favored by other cosmological grounds (see calculations by Cen et al. 1994). According to modern data, the maximum star formation starts z ~ 2-2.5, which corresponds to the dictionary definition of dark energy density. In subsequent years, attempts were made not only to register the presence of dark energy, but also to investigate the possible evolution of the contribution of their dark energy .

7. High energy neutrino sources search.

Astrophysicists have long studied the flows of particles coming from space. Cosmic ray energy reaches 10^{19-20} eV and higher. We still do not know exactly which astronomical objects are their source. Such particles cannot come from Metagalaxy, since charged particles are deflected by an intergalactic magnetic field, and at energies greater than 10^{19} eV, the Universe becomes opaque due to the presence of CMB radiation - the Greisen-Zatsepin-Kuzmin effect [106,107]. But one particle of any energy can still permeate the entire Universe without significant absorption and deviation - this is a neutrino.

In the XXI century physicists built neutrino "telescopes" of gigantic sizes in Antarctic ice - the IceCube project [65]. This one, in mountain tunnels - the Baksan neutrino observatory [108], deep under water - the French installation ANTARES at the bottom of the Mediterranean Sea and the Baikal neutrino observatory in the cleanest and deepest lake in the world. And such neutrinos were found. In 2013, the IceCube neutrino observatory provided the first evidence of a high-energy neutrino flux (> 100 Tev) of cosmic origin. The distribution of these neutrinos turned out to be isotropic across the sky, which testified in favor of their metagalactic origin. However, the source of ultrahigh-energy neutrinos is still one of the most exciting mysteries in the universe. An electrically neutral neutrino, unlike ultrahigh-energy cosmic rays, propagates freely throughout the universe without deviating in an intergalactic magnetic field or interacting with relict cosmic radiation. Thus, the neutrino trajectory indicates the direction to its source. By the middle of the first decade of the XXI century. several neutrino installations learned to reduce processing time to several tens of seconds and began to transmit the coordinates of neutrino squares of errors via the Internet[65,86]. From this moment (2015), the MASTER network began to search for high-energy neutrino sources recorded by the IceCube installation (GCN 18231, GCN 18240; ATel 7987, GCN 19362). Unfortunately, the scattering of light in ice or water, which are the working body of neutrino detectors, leads to a deterioration in localization accuracy and the localization region in the sky reaches several square degrees.

Since 2015, the MASTER began to receive target designations from ANTARES [86]. Until 2022, MASTER received signals of several gigaelectronvolts from a medium-energy neutrino detection unit located on Baksan (North Caucasus) - BUST [108].

Just two years later, we discovered the closest correlation to the time of registration of neutrinos with a known early astronomical object [35].

Usually the localization region is of the order of 1 angular degree.. Even if we count only super-powerful active galactic nuclei that shoot exactly at the Earth - blazars, then there will be an average of about two of them in each such error box. Therefore, simply detecting a blazar in an errorbox of neutrinos is not proof that it is the blazars that are the source of their origin. The proof would be some non-standard phenomenon at the alleged source, close in time to the neutrino event.

The first candidate for such objects was blazar TXS 0506 + 056, which fell into the error square of the neutrino event IceCube 170922A. Blazar was removed from us at a distance of ≈ 3.7 billion light years (redshift $z = 0.34$).

So, on September 22, 2017, having received a notification from IceCube 40 seconds after the neutrino event, the MASTER-Tavrida telescope took the first three images starting from September 22, 2017 (20 hours 55 minutes 43 from UT). The field of view of the MASTER telescope completely covers the final field of view of IceCube. After 2 hours, the brightness of the stream from the blazar doubled and it returned to its usual brightness.

In the standard model, it is accepted that blazar radiation is formed in a relativistic stream directed at us. The gamma factor of the relativistic jet is moderate, [illegible] ≈ 10. In the shock wave at the front of the jet, protons are accelerated to ultra-high energies, which in turn collide with target photons and generate the production of pions. The decay of pions, in turn, generates muon neutrinos (which is recorded by IceCube) and high-energy gamma photons (recorded by the Fermi gamma-ray observatory). For about 2 weeks around the time of detection of neutrino events, the gamma luminosity in the range of 0.1-100 GeV was 1.3×10^{47} erg/s [65]. Note that the neutrino luminosity of the quasar was approximately $L \approx 4 \times 10^{47}$ erg/s, which is noticeably higher, but still obviously close to gamma luminosity. This is not surprising, however, because neutrinos and gamma emission share the same energy source -- a source of high-energy protons accelerated by a shock wave at the front of a relativistic jet formed by a central supermassive black hole. Two branches of the reaction between protons and photons (targets): give neutral and charged pions, which then decay into gamma photons recorded by the Fermi observatory, and muon neutrinos ν_μ. Both branches of the reaction give rise to pions and therefore have a threshold character [70]. Let us suppose that pions are actually born as a result of the collision of relativistic protons with target photons γ[illegible]. Note that neutrinos and gamma photons carry away several percent of the proton energy. Hence, the neutrino luminosity of blazars is determined just by the birth rate of charged peonies. Suppose that the same protons accelerated at the shock wave front of the relativistic clot are a source of optical radiation due to the synchrotron mechanism in the magnetic field of the relativistic clot (Paliya et al., 2020). Then it should be expected that with an increase in the neutrino flux, due to the disappearance of PeV protons, the optical radiation of the blazar will also fall.

7.1. The High Energy Neutrino IceCube-211208A and Opticaly Anxious Blazars Blazars PKS 0735+17

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]. MASTER-Amur optical robotic telescope was pointed to the IceCube-211208A error box 682 sec after trigger. MASTER real time auto detection system discovered some flashes of MASTER OT J073807.40+174219.27,11 coincident with Blazar PKS 0735+17 which brightening up to 14.1m (0.2m/12h) next nights of observations [43]. Afterwards, observations were additionally conducted by MASTER-Kislovodsk, -Tavrida, -OAFA, -IAC, -SAAO and -Tunka. 8 hours after the neutrino event detection, MASTER-OAFA has imaged blazar PKS 0735+17, located slightly outside the 90% localization error-box. Observations by other observatories confirmed that the

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blazar was flaring in gamma, X-ray and radio diapasons. One can see the detailed light curve based on MASTER data at Figure 13a.

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 magnitudes. It was found that the study of only 90% of localization leads to the exclusion of possible sources of neutrinos from consideration.

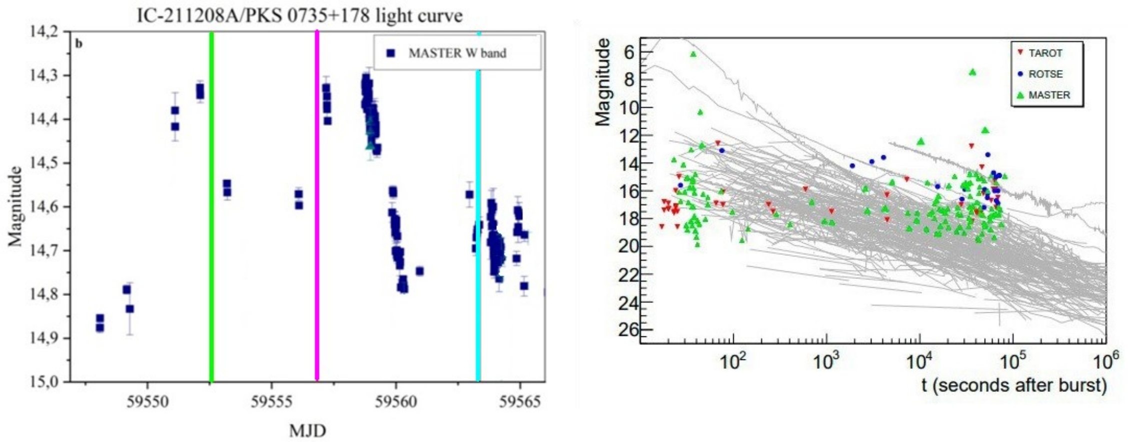

Figure 13a (left). MASTER light curve for PKS 0735+178 for a ~30 day period, magenta line – IceCube and BAIKAL-GVD detection of IC-211208A, green line – BAKSAN detection, blue line – ARCA detections. 13b(right) Comparison between archived optical R band and uncorrected light-curves for 301 GRBs detected during the 1997-2014 period obtained from the GCN circulars (grey lines) and the magnitude limits inferred for the 208 neutrino alerts during the 2009-2021 period. Red, blue and green markers indicate upper limits on GRB afterglow magnitudes for neutrino alerts set by TAROT, ROTSE and MASTER, respectively [109].

7.2 Multi-wavelength follow-up of ANT150901A

High-energy neutrinos could be produced in the interaction of charged cosmic rays with matter or radiation surrounding astrophysical sources. To look for transient sources associated with neutrino emission, a follow-up program of neutrino alerts has been operating within the ANTARES Collaboration since 2009 [109]. This program, named TAToO, has triggered robotic optical telescopes (MASTER, TAROT, ROTSE and the SVOM ground based telescopes) immediately after the detection of any relevant neutrino candidate and scheduled several observations in the weeks following the detection.

In September 2015, ANTARES issued a neutrino alert and during the follow-up, a potential transient counterpart was identified by Swift and MASTER. A multi-wavelength follow-up campaign has allowed to identify the nature of this source and has proven its fortuitous association with the neutrino. The return of experience is particularly important for the design of the alert system of KM3NeT, the next generation neutrino telescope in the Mediterranean Sea.

Assuming the hypothesis that all the neutrinos are issued from GRBs, and by comparing these upper limits with optical afterglow light curves of gamma-ray bursts, it becomes possible to test the GRB association for each neutrino alert. Figure 13b shows the optical afterglow light curves of GRBs in R band detected from 1997 to 2014 (taken from GCN circulars) and the optical upper limits obtained for each neutrino alert. Note that the comparison between the R and clear observations is not direct, as there is typically less than about 0.5 magnitude difference and depends on the telescope camera and filter. But this small difference does not change the overall conclusion of the studies.

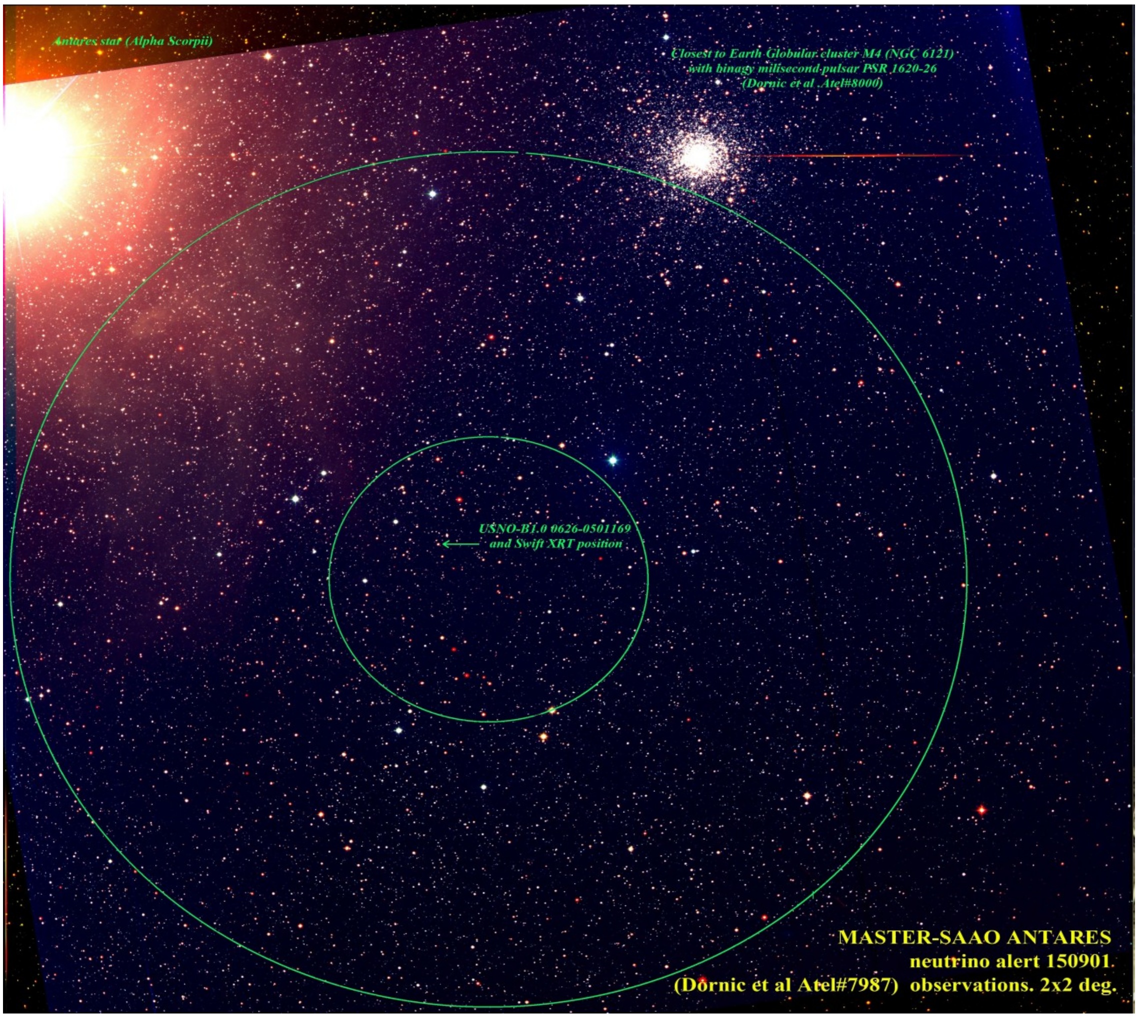

Figure 14. Field of view of MASTER corresponding to ANT150901A. The 2 circles have a radius of 0.3 and 0.9 degrees.

In the X-ray follow-up, a bright and transient counterpart candidate was found for a single neutrino alert: ANT150901A. The associated neutrino had an energy of about 90 TeV with a 1σ range between 20 − 300 TeV. Observations with XRT started in September 1st, 2015 at 16:38:42 UT (namely 9 hours after the neutrino trigger). In parallel, optical follow-ups by the MASTER telescopes [86] began 9 hours 45 minutes after the neutrino detection. The location corresponding to the neutrino direction was followed since the first day with two telescopes in South Africa and Canary Island with the R, B, and V filters. This direction was regularly followed by one of the MASTER telescopes during the 8 subsequent days. No optical transient candidate was found in the observations down to a magnitude of 18.67 (60 s exposure). At the position of the X-ray source, MASTER identified a bright star (USNO-B1.0 0626-0501169) of magnitude 12.3 with a light curve showing no flux nor color variations just after the time of the alert [86]. Figure 14 illustrates the field of view of MASTER. The globular cluster M4 is 0.97◦

away and the Antares star (Alpha Scorpii) is at a distance of 1.2^0 away from the ANT150901A neutrino direction.

8. The Detection and Investigation of Exoplanets with MASTER Global Network Telescopes

We designed the method for detecting exoplanets in the image archive obtained by telescopes of the MASTER Global Network since 2002. The unique archive represents homogeneous photometric data obtained over 20 years for the northern (MASTER-Amur, -Tunka,-Kislovodsk, -Tavrida, -IAC, -OAGH) and 11 years for the southern sky (MASTER-OAFA, -SAAO). Algorithm of gamma-ray burst error box observation on the MASTER wide-field telescopes make it possible to detect transit phenomena and find exoplanets in archival data. The peculiarities of observing the error fields of gamma-ray bursts on wide-field telescopes MASTER make it possible to detect transit phenomena and find exoplanets in archival data. The article provides the results of photometric analysis of the candidate for exoplanets TESS TOI-3570.01. The Figures 15a,b present the results of a photometric analysis of the TESS exoplanet candidate TOI–3570.01 and MASTER archive light curve of TESS exoplanet candidate TIC 127115861.01.

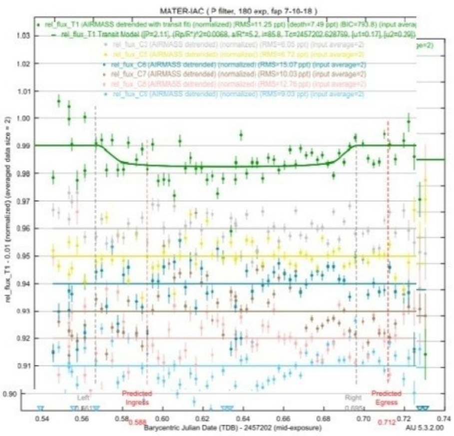

Figure 15a. MASTER light curve of TOI-3570.01 in the P band of June 29, 2015, obtained by the MASTER-IAC telescope. Exposure duration is 180 s, averaging over two pieces (i.e. 360s). Green dots show photometry results corrected for atmospheric absorption, green curve shows transit model built by AstroimageJ program [110]. The characteristics of the planet obtained from the model are indicated at the top of the graph. Transit is clearly visible on the graph.

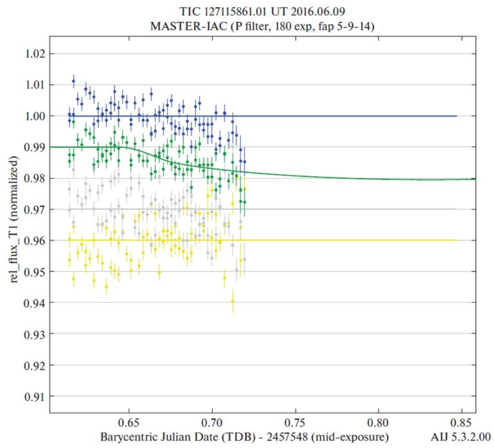

Figure 15b. MASTER archive light curve of TESS exoplanet candidate TIC 127115861.01 in unfiltered band, obtained on 2016-06-09 by MASTER-IAC telescope. Blue dots represent raw photometric data, green dots—detrended using transit fit data, grey and yellow—comparison stars.

Studies of exoplanets by the transit method using the MASTER network have been carried out before. For example, a program for searching for exoplanets on the MASTER-Ural telescope was implemented several years ago . It was based on the successive observation of several sites in the sky with successive re-guidance between them. As a result, two candidates were discovered [114].

An alternative program for searching and researching exoplanets was developed based on the archive of the MASTER MSU Global Network. It is based on the study of the archive and the identification in the data series obtained by robotic telescopes of transits of both known candiates into exoplanets and new extrasolar planets. The archive was examined for long rows of observations and more than 900 such unique rows were identified. The study of candidate exoplanets discovered by the TESS space observatory in these fields has begun. Also, the MASTER Global Network of Robotic Telescopes has actively connected to observations of exoplanet transits as part of the ExoFOP-TESS program. The MASTER-Kislovodsk, -Tavrida, -Tunka and -SAAO telescopes observed the transits of candidates within the framework of this program. Results of the photometric analysis of candidates for exoplanets of TESS TOI-3661.01, TOI-3922.01, TOI-1875.01, TOI-5615.01, TOI-2836.01, TOI-3788.01, TOI-3689.01, TOI-3779.01, TOI-4436.01, TOI-3854.01, TOI6386.01, TOI-3770.01 are loaded into the ExoFOP database.

Also we can use MASTER large archive database for analysis and transit event search.

In order to detect transiting exoplanets in the MASTER network archive, we selected the fields that were observed by MASTER telescopes continuously for a long time in the fields of Swift gamma-ray bursts alerts. MASTER network has own planner, that controlled all type of alerts from GCN and other targets. The fields of gamma-ray bursts, detected by Swift [111], that were observed (their errorboxes are fully covered by 4 sqaure degrees of each MASTER tube) from alert time to sunrise, if there are no high level alerts (Fermi-LAT, Integral, LIGO/Virgo since 2015, ANTARES and IceCube since 2015. So we have long sets of images for each Swift alerts, that were analyzed and the example of transit part for TESS exoplanet candidate TIC 127115861.01 is presented at Figure 15b.

9. Potentially dangerous asteroid Svarog (up to 900 m).

The list of comets and potentially dangerous asteroids of the MASTER Global Network contains more than 10 objects (http://observ.pereplet.ru/hazardMASTER.html).

One of the largest potentially dangerous asteroids discovered by MASTER is 2015UM67 [112] (Figure 16ab, http://master.sai.msu.ru/static/2015UM67.gif), and we proposed to name it after the ancient Slavic god of fire and blacksmithing Swarog. He is mentioned in the Tale of Bygone Years (beginning of the 12th century) as the father of Dazhdbog. Marked in the toponymy of Western and Eastern Slavs, as well as Indo-Aryans. Maybe he will help us "weld" the MASTER with a diameter of 1000 mm? In 2015, researchers using the MASTER network discovered a dangerous asteroid with a diameter three times larger than that of the famous asteroid Apophis. For our project, the search for potentially dangerous asteroids is a byproduct that demonstrates the capabilities of the MASTER software. But it should be emphasized that we discover dangerous asteroids automatically.

Of course, we cannot use the MASTER on this topic 100%, since the search for moving bodies requires three times passing the same sites. Here, read the telegram MPEC 2015-V01[112]: "Russian robot telescope MASTER, located in South Africa (international code K95 - the line is marked with an asterisk). Discovered a giant potentially dangerous asteroid (not to be confused with NEO (Near Ear Object - objects close to Earth). " The Italian linguist M. Henrietti also admits the possibility of directly borrowing the name Svarog into the Slavic language from Indo-Aryan. "However, now, after the advent of the science of DNA genealogy, it can be considered proven that everything happened the other way around: Indo-Aryans came to India from the territory of modern Russia, Indo-Aryans and Slavs are descendants of a common ancestor" [113].

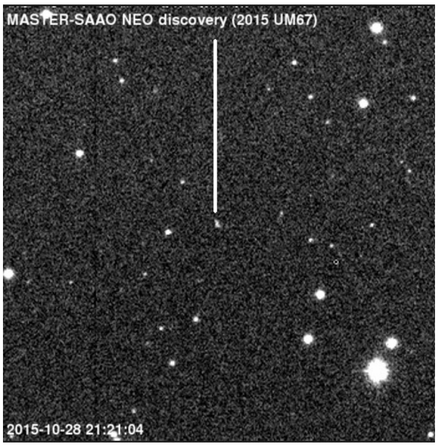

Figure 16.a MASTER 2015UM67 discovery image (Svarog)

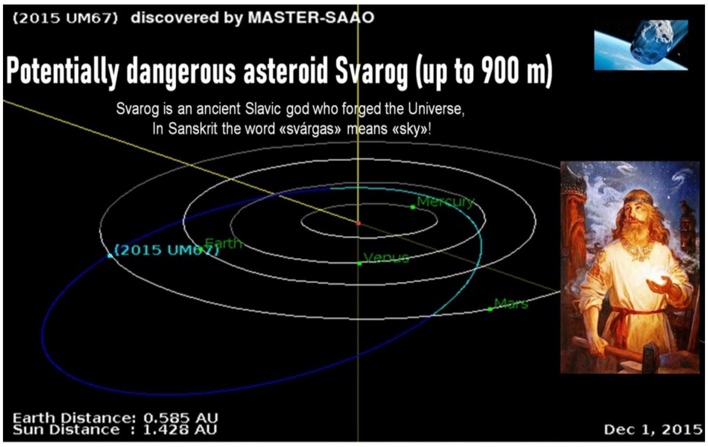

Figure 16b. Svarog is an ancient Slavic god who forged the Universe

Its diameter can reach 1 km (according to NASA calculations)! Such a monster is almost 27 times more massive than Apophis, the approach of which is expected and feared in the second half of the 20s. XXI century Secondly, the period of revolution around the Sun almost coincides with the Martian year: two Earth years.

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]. The highlights of last year were presented in this paper.

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