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MASTER GLOBAL ROBOTIC NET: NEW SITES AND NEW RESULT

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RESUMEN

La Red Global Robótica MASTER incluye la colaboración con España (IAC), Sudáfrica (SAAO) y Argentina (OAFA) con el objeto de producir alertas astrofísicas, seguimiento y observaciones cartográficas enfocadas a diversos campos astrofísicos: descubrir polarización óptica temprana en estallidos de rayos-gamma (GRB 150301B, GRB 150413A, GRB160625B, GRB 161017A, GRB 161023A, etc.), investigar posibles fuentes de ondas gravitacionales (LIGO/VIRGO) y alertas de neutrinos de altas energías (IceCube, ANTARES) en zonas de error de gran diámetro, descubrimiento de GRBs huérfanos, supernovas Ia para caracterizar la energía oscura, otras SNe, novas, novas enanas, etc. para estudiar sus carácterísticas durante los estallidos. MASTER investigó más de 400 GRBs, investigando GW 150914, y más de 60 alertas de neutrinos de muy alta energıa, descubriendo más de 1300 fuentes esporádicas ópticas así como la polarización variable en V404 Cyg.

ABSTRACT

MASTER Global Robotic Net is the unique Russian with collaborators of Spain (IAC), South Africa (SAAO) and Argentina (OAFA) astrophysical project for alert, follow-up and survey observations to solve all modern key astronomy tasks: to discover the prompt and earlier optical emission polarization from gamma-ray bursts (GRB 150301B, GRB 150413A, GRB160625B, GRB 161017A, GRB 161023A, etc), to investigate possible sources of gravitational-wave alerts (LIGO/VIRGO) and high energy neutrino alerts (IceCube, ANTARES)in large error-boxes; to discover the the orphan bursts, Supernovae Ia for dark energy characteristics; other SNe, Novae, dwarf novae, etc. to study their characteristics during the outbursts. MASTER investigated more then 400 GRBs, made the most input to optical support of GW150914, investigated more then 60 very high energy neutrino alerts, discovered more then 1300 optical transients, discovered optical polarization variability of V404Cyg

Key Words: gamma-rays burst: general — polarization

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1. MASTER GLOBAL ROBOTIC NET

MASTER Global Robotic Net (http://observ.pereplet.ru, (Lipunov et al. 2010; Kornilov et al. 2012)) consists of 7 twin fast pointing identical wide-field telescopes MASTER-II with BVRI and polarization filters (2x4 square degrees, 20-21m per 180s exposition) on 3 continents, that gives us possibility to have 24h photometry in the same system in winter time. Each observatory also includes MASTER Very Wide Feld Cameras (14m per 1s exposition,800 square degrees). There is also MASTER-SHOK very wide field cameras on the board of MSU space satellite Lomonosov (Amelyushkin et al. 2013; Sadovnichiy et al. 2013) with 1000 sq.degrees field of view as a space part of MASTER network.

MASTER-II twin tubes can observed different fields simultaniousely in open mode (8 sq.deg, that let us observe large FERMI, LIGO, IceCube, ANTARES error-boxes in real-time) or one field (4 sq.deg.) in different polarizations and/or BV,RI simultaniousely (closed). These telescopes are very suited for alert/ follow up programs such as GRB prompt and earlier optical polarization observations, gravitational-waves error-boxes investigations (MASTER made the most input to optical support

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Fig. 1. MASTER Global Robotic Net telescopes location

Fig. 2. MASTER-SAAO wide-field and very wide field telescopes

of GW150914 LIGO event (Abbott et al. 2016a).

Identical MASTER-II telecopes are located on 3 continents: russian sites MASTER-Amur, MASTER-Tunka, MASTER-Ural, MASTER-Kislovodsk; MASTER-SAAO (mounted in December 2014) in South African Astronomical observatory ; MASTER-IAC (mounted in June 2015) at Teide observatory, Tenerife, Spain; and MASTER-OAFA (mounted in May 2016) at Observatorio Astronomico Felix Aguilar of San Juan National University in Argentina. Each MASTER observatory provides a survey speed of 128 deg^2 per hour with a limiting magnitude of 20 mag on dark, moonless nights.

The main feature of modern physics experiment is the time of information reduction. To investigate the nature of gamma-ray bursts phenomena we must observe GRB error-box during its gamma emission, i.e. investigate prompt optical observation. To investigate large areas of gravitational-wave events and very high energy neutrino sources events you must be ready to observe their error-boxes in alert mode and to have on-line reduction software to have possibility of spectroscopy of discovered new optical sources, that can be connected with such alerts. It means, that all alert and follow-up observations must be fully robotized and the reduction of images must be in real-time. Such telescopes we called robotic telescopes. We introduce MASTER Global Robotic Network of fully robotic alert, follow up and survey observations by MASTER-Amur, -Tunka, -Kislovodsk, -Ural, -SAAO, -IAC, -OAFA wide field telescopes.

MASTER developed own real-time software. In fully automatic mode this software operates the network of MASTER telescopes, observes in alert, follow up and survey mode and extracts all information from MASTER wide-field images (4 square degrees) during 1-2 minutes after CCD readout (it means, that reduction time is shorter then usual exposition) with full astronomical classification of each optical sources in each images. This time includes both prime reduction (bias, dark, flat field) and photometry and astrometry with USNO-B1 known stars. It means, that MASTER software extract all information about all optical sources with classification of every sources, extraction of new ones (optical transients) and with detection of parameters for mooving objects with automatic alerts to Minor planet center about known and unknown mooving objects . This software let us to discover more then 1300 optical transients of 10 types of nature for last several years [10] in real-time, to follow-up more then 60 ANTARES and IceCube alerts, to investigate more then 400 GRB error-boxes, to discover optical polarization variability of V404Cyg (Lipunov et al. 2016b).

2. MASTER AND GLOBAL PHYSICS EXPERIMENTS: LIGO, ANTARES, ICECUBE

MASTER is fast pointing alert and follow up system, located both in North and Southern hemisphere, that make it very suitable to investigate large fields of view in short time with online optical transients detection inside these error-boxes.

This led us to join the LIGO/VIRGO Collaboration follow-up program (Abbott et al. 2016a,b) to detect possibly optical counterparts of gravitational wave's events and to win in GW150914 optical support, made the most input to it (Abbott et al. 2016a).

After we received the map of probability for the error box of the first gravitational-wave advanced LIGO trigger GW150914 (Singer et al. 2015a) MASTER was starting to inspect the initial error-box during next month at the following sites: MASTER-Amur, -Tunka, -Kislovodsk, -IAC telescopes (North-

[10]http://observ.pereplet.ru/MASTER_OT.html

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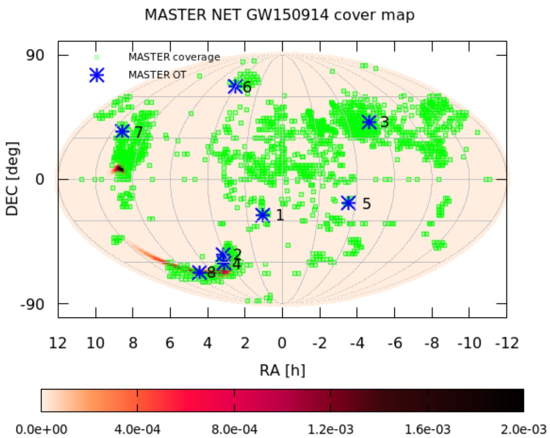

Fig. 3. MASTER coverage map of GW150914 inspection

ern hemisphere) and by MASTER-SAAO at Southern one, where the weather and night-time conditions were permitted. Up to the 22 September 2015, we took about 9500 images which covered more than 5200 square degrees of sky down to a 19.9 unfiltered magnitude limit (Lipunov et al. 2015a,b). More than 920 images were located inside the eventual error box of GW150914 and cover 590 square degrees. Each area was covered several times. These results were introduced with LVC electromagnetic collaboration (Abbott et al. 2016a; Lipunov et al. 2016)

The MASTER-SAAO twin robotic telescope of the Global MASTER Robotic Net (Lipunov et al. 2010) started inspecting of the aLIGO trigger GW150914 error box 61.25h after the GW detection, at 2015-09-16 20:18:11 UT. But there were 30 images starting from 2015-09-15 03:24:22 UT in MASTER-SAAO database (made during the usual MASTER-SAAO survey) taken on September 14, 15, and 16, 2015. These images cover 16 square degrees up to 19.0m unfiltered magnitude limit. So the first optical images were obtained by MASTER 1.094d before the notice letter and 17.6 h after the GW150914 trigger.

During the inspection of GW150914 , the 5-sigma upper limit on our sets was about 18.4 mag - 19.9 mag (Lipunov et al. 2015a,b). On this first night we observed 212 square degrees, imaged 3 times for each field during ∼2 hours. The LMC and Milky Way are near the center and east edge of the error region, respectively.

MASTER auto-detection system discovered 8 optical transients during the 8 days inspection of GW150914 alert. Five of these eight optical transients are located in areas with very low probability (which, however, is greater than zero in all cases).

Fig. 4. MASTER OT J040938.68-541316.9 discovery unfiltered image

The probability of their association with the gravitational wave source is extremely low (see figures in (Lipunov et al. 2016)).

3 of OTs are located inside the 3-sigma of the initial and final square error:

MASTER OT J070747.72-672205.6 is a dwarf nova outburst (UGem types) (Gress et al. 2015b) discovered on 2015-09-21.99535 UT with unfiltered (w=0.2B+0.8r calibrated by thousands USNO-B1 stars) m=16.9,

MASTER OT J042822.91-604158.3, dwarf nova outburst, discovered on 2015-09-16.909UT, m=18.2

and MASTER OT J040938.68-541316.9 - supernova, discovered on 2015-09-16.87912 UT (Gress et al. 2015a) with unfiltered m=17.3m. It was seen in 5 images, the reference image without this PSN was taken on 2015-02-14.89772 UT with an unfiltered mlim=20m. We classified it as a PSN from its location in 0.9”W, 3.6” N of the galaxy PGC421615 (Btot=18.4m).

This PSN was observed several times during the regular MASTER-SAAO survey on September 24, 2015; October 17, 18, and 19, 2015; November 25, 2015, and on January 26 and February 18, 2016. Several images were available for each night. The supernova appears to have reached its maximum light between the observations of September 16 and October 24, 2015 (Lipunov et al. 2016). We took deep photometric images in *B, g’, r’, i’* and *z’* images of the area on 3 March 2016 with the SALTICAM CCD camera of the 10.4-meter Southern African Large Telescope (SALT) at the SAAO and the supernova can be seen

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clearly in different filters, 170 days after its discovery, but the scarcity of available photometric data prevents a determination of the supernova type. Analyzing the photometric data for different types of SN behaviour [11] , we can conclude that it can be a type Ib/c or IIp supernova discovered near maximum light, and we should tell, that the considered supernova explosion could be on the 14 of September 2015. On 10 March 2016, we obtained low resolution (∼300) spectrum, covering 3400-10000 Angstroms, of the host galaxy PGC421615 in a 1800 s exposure, resulting in a redshift determination of z=0.054, implying a relatively close galaxy (GW150914 redshift is $z = 0.09^{+0.03}{}_{-0.04}$ (Abbott et al. 2016a)).

MASTER also collaborates with IceCube and ANTARES physics experiments, following up the optical support for about 100 very high energy neutrino alerts (Dornic et al. 2015a,b,c).

The example is MASTER inspection of Antares neutrino Alert150901.32 (ra=16 25 42 dec=27 23 24 r=1.726600). MASTER-SAAO robotic telescope automatically started on 20150901 17:23:48 UT with 18.5-19.8 (180s exposition), and 20.6 on the sum (540s exposition) unfiltered optical limits. Observations were continuing on 2015-09-03 17:13:59 (sunset) up to 2015-09-03 21:21:59 (it becames cloudy) in parallel MASTER twin tubes in BV and RI filters. The optical limits were the following: in B filter on single images was mB_{lim}=19.1 (180s), 19.6 on sum (540s), in V filter mV_{lim}=19.3(180s), 19.9 on the sum(540s), in R filter mR_{lim}=19.0m (60-180s), mR_{lim} = 20.3 on sum (1800s), in I mI_{lim} = 18.0 on single images(180s), 18.5 on the sum (540s).

MASTER-IAC automatically started inspect observations on 2015-09-01 21:02:44, observed up to 2015-09-01 21:17:34 with unfiltered m_{lim}=19.8(540s). Observations were continuing in B and V on 2015-09-03 20:08:40-22:09:12 with mB_{lim}=19.8 (180s), and mV_{lim}=18.6 (180s).

MASTER-Kislovodsk robotic telescope automatically started inspect survey on 2015-09-03 16:39:11 UT at sunset (object altitude was 14.85, the Sun altitude was -10.65), and were continuing up to 2015-09-03 18:04:47 when the objects set. The first hour we have seven 30-s expositions with bad weather condition (mV_{lim}=14.1). Unfiltered observations were continued on 2015-09-03 17:21:39 (11.01 deg object altitude) with m_{lim}=18.4 (180s).

MASTER-Tunka robotic telescope automatically started inspection also at sunset on 2015-09-03 12:40:59 UT. The object altitude was 6.86 , the Sun altitude was -8.12.

[11] https://c3.lbl.gov/nugent/nugent_templates.html

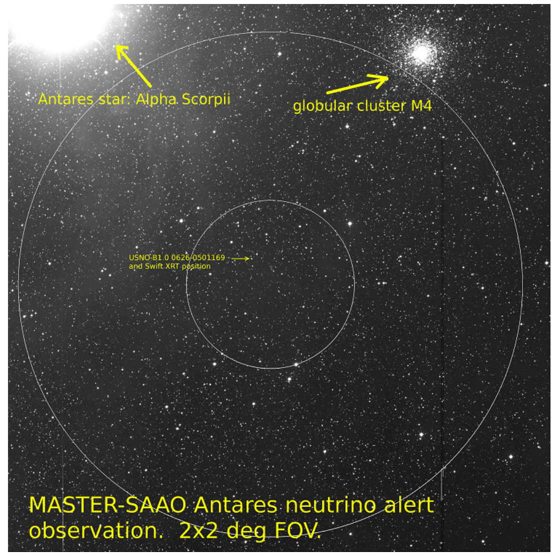

Fig. 5. MASTER images of the Antares error box

No optical transient were found inside the neutrino error box.

The Swift location 16h 26m 02.1s -27d 18m 14s was difficult for observations from Nothern hemisphere (MASTER-Kislovodsk, -Tunka, -Ural, -Amur). It could be observed only at sunset near the horizon. There was a bright star USNO-B1.0 0626-0501169 inside Swift XRT error box and MASTER-SAAO has optical light curve of it in BVRI [12]

The source was stable in all four band as well as its color. The average color was B-V = 0.93 ± 0.06, R-I = 1.07 ± 0.03. And our observations in January, May and September 2015 don't show the constant behaviour (unfiltered 12.36 ± 0.03 in January; 12.32 in May and 12.32 in September). Thus it can be argued that the brightness of the star has not changed by more than 3%. Since the X-ray emission occurs near the stellar photosphere, so due to the heating effect of its brightness should slightly increase. The observed brightness of the star persistence restricts the change in X-ray flux in September compared with a May and January: $F_x/F_{opt} < 3\%$. Consequently, $F_x < 7e^{-11} erg/s$. This means that the X-ray heating can not cause optical variability more than 0.003 magnitude. It seems the X-ray is result of the X-ray flare activity of the star

There is Globular Cluster M4 (NGC621) with millisecond pulsar and possible massive black hole inside ANTARES alert 3-sigma error box

By the way there is star Antares (1.3 degrees from center ANTARES error box, but outside!). So, we

[12] `http://master.sai.msu.ru/static/master_antares_alert_150901.png`

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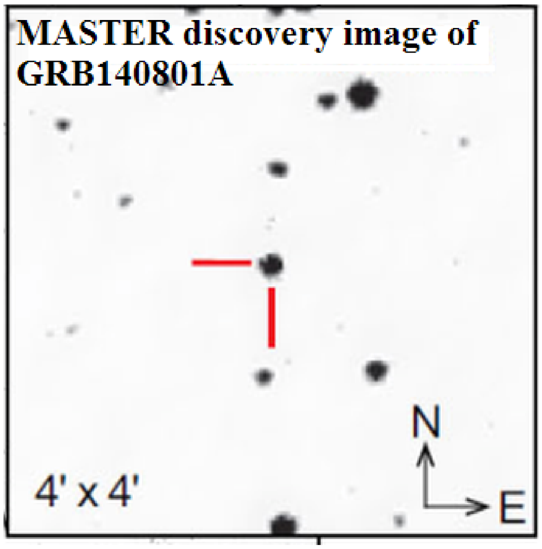

Fig. 6. MASTER discovery image of GRB140801A: the result of own real-time auto-detection software

propose M4 (with relativistic objects inside) is the possible source of the neutrino, which created after cosmic partical acceleration.

3. MASTER GRB PROMPT OPTICAL EMISSION OBSERVATIONS

The study of gamma-ray bursts remains to be a very important astrophysical goal. GRB investigations by Global astrophysical experiments (GCN, Fermi, Swift, MAXI, Lomonosov, etc. and ground robotic and spectroscopic telescopes collaboration, for ex., up to now MASTER investigated more then 400 error-boxes of GRB) provide an excellent opportunity for developing new software dedicated to optical-transient (OT) detection in wide-field sky regions (Lipunov et al. 2016c).

MASTER is the only observatory that automatically react to *most* Fermi alerts. GRB 140801A was one of the few GRBs whose optical counterpart was discovered by MASTER own auto-detection software solely from its GBM localization (wide-field error-box). The optical afterglow of GRB 140801A was discovered by MASTER 53 sec after receiving the alert, making the fastest optical detection of a GRB from a GBM error-box. Spectroscopy obtained with the 10.4-m Gran Telescopio Canarias and the 6-m BTA of SAO RAS reveals a redshift of $z = 1.32$. Optical and near-infrared photometry of GRB 140801A using different telescopes with apertures ranging from 0.4-m to 10.4-m .

GRB 140801A was a typical burst in many ways. The rest-frame bolometric isotropic energy release and peak energy of the burst is $E_{\rm iso} = 5.54^{+0.26}_{-0.24} \times 10^{52}$ erg and $E_{\rm p,rest} \simeq 280$ keV, respectively, which is consistent with the Amati relation. The absence of a jet break in the optical light curve provides a lower limit on the half-opening angle of the jet $\theta = 6.1$ deg. The observed $E_{\rm peak}$ is consistent with the limit derived from the Ghirlanda relation. The joint *Fermi* GBM and Konus-*Wind* analysis shows that GRB 140801A could belong to the class of intermediate duration. The rapid detection of the optical counterpart of GRB 140801A is especially important regarding the upcoming experiments with large coordinate error-box areas.

GRB 140801A at could be classified as an intermediate gamma-ray burst by its duration, but it has a hardness ratio characteristic for long GRBs (Horvath et al. 2006). A negligible spectral lag is not unknown for long GRBs, but it is rather rare — and more typical for short GRBs. Though this burst seems to have a high peak luminosity, which would agree with the small lag. Based on results by (Wang et al. 2013), we find that the optical afterglow of GRB 140801A lies in the brightest 20% of observed optical afterglows at 100 s after the burst trigger. The optical light curve behaviour can be described by an early, steep decline $t^{-1.42\pm0.04}$ which becomes slower ($t^{-0.81\pm0.04}$ in V and $t^{-0.82\pm0.01}$ in R bands) after approximately 2 hours. We conclude that there is no evidence of jet break in our optical data. Spectral modeling of the optical and X-ray data around 0.63 d, together with the derived slope of the optical emission, favour a model in which the emission is generated by the forward shock spreading into a homogeneous interstellar medium.

For GRB 150301B and GRB 150413A MASTER observed the early optical linear polarization (Gorbovskoy et al. 2016c; Pruzhinskaya et al. 2014) and found the minimum polarization for GRB 150301B to be 8% at the beginning of the initial stage, whereas we detected no polarization for GRB 150413A either at the rising branch or after the burst reached the power-law afterglow stage. This is the earliest measurement of the polarization (in cosmological rest frame) of gamma-ray bursts. The primary intent of the paper is to discover optical emission and publish extremely rare (unique) high-quality light curves of the prompt optical emission of gamma-ray bursts during the non-monotonic stage of their evolution. We report that our team has discovered the optical counterpart of one of the bursts, GRB 150413A.

(Vestrand et al. 2005) noted that two behavior types of early optical emission are observed for gamma-ray bursts. In some cases optical emission

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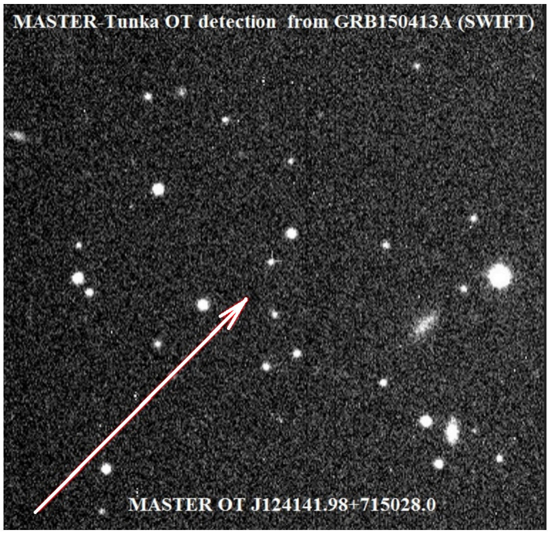

Fig. 7. MASTER optical counterpart discovery of GRB150413A.

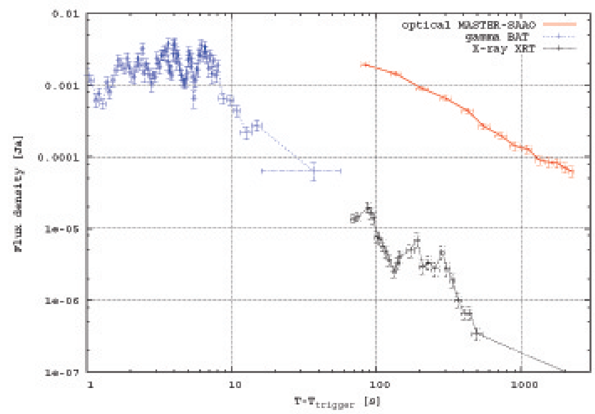

Fig. 8. Optical (MASTER), X-ray and gamma (SWIFT) light curves of GRB150301B

varies in concert with gamma-ray flux, whereas in other cases the optical light curve is totally uncorrelated with the gamma-ray flux and usually consists of a smooth rise followed by power-law afterglow. We earlier observed both types of such behavior (Gorbovskoy et al. 2012). Suggesting that in the former case we are dealing with the optical emission arising in the internal shock region, where it is generated simultaneously with the gamma-ray emission. In this case the optical light curve reflects the internal properties of the relativistic magnetized jet (ultra-relativistic ejecta driven by the GRB) and detection of its polarization would provide unique information about the jet structure. GRB 150301A, GRB 150413A belong to the 2nd type. The optical emission of the second type may be associated with a different region of the jet (in the standard fireball model), which forms as a result of relativistic jet colliding with interstellar gas compressed in the bow shock or with the stellar wind of the progenitor.

4. CONCLUSION

We report the current state of MASTER Global Robotic Net with 3 new observatories at SAAO, IAC and OAFA and presented the most important scientific results, including discovery of GRB prompt optical emission, MASTER input (the most) to optical support of GW150914 discovery, MASTER investigation of ANTARES neutrino alerts, detection of optical polarization variability of V404Cyg.

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